Summary of Progress *of the* GEOLOGICAL SURVEY OF GREAT BRITAIN *and the* Museum of Practical Geology for the Year 1932

PART II

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Department of Scientific and Industrial Research

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Geological Survey of Great Britain

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I.—THE GEOLOGY OF THE MENEAGE

By Sir John S. Flett, K.B.E., F.R.S.

Plate I ; Text-figures 1 and 2.

THE district of Cornwall known as the Meneage lies on the south side of the Helford River and on the north of the Lizard district. It comprises three parishes, Mawgan in Meneage, St. Martin in Meneage and St. Anthony in Meneage. The name is believed to be derived from a Cornish word meaning ' the place of stones.' At the present time it is a well-cultivated and fertile country, not particularly stony, especially when compared with the Lizard district to the south of it, where the rocky knolls of serpentine stand up through the heather of the downs, and the fields upon the gabbro are strewn with great residual blocks, weathered out of the subjacent rock. It is probable, however, that in early times many masses of white quartzite were scattered over the surface. They belong to the Ordovician or Gorran Quartzite, and in large numbers have been broken up to form the field walls so characteristic of Western Cornwall, and to serve as road-stones, a use for which they are still much employed. In strict parlance the Meneage is distinct from the Lizard, and the boundary between the two corresponds very closely with the northern edge of the Lizard rocks.

In the variety and complexity of their geology few districts of Cornwall rival the Lizard and Meneage. They contain not only the many facies of the crystalline and metamorphic rocks of the Lizard but also a set of Palaeozoic formations typical of the West of Cornwall, and also the later granites, elvans and minettes. The geological literature written on this country is very extensive and, owing to the perplexing nature of the outcrops, it reveals a great diversity of opinion regarding the structure, age and sequence of the rocks. It was first surveyed by De la Beche on the one-inch scale and published as Old Series Sheets 31 and 32 in 1839. The six-inch survey of the Lizard was executed by the writer of this contribution, and of the Meneage by the late J. B. Hill, in the years 1906 to 1910, and published as New Series Sheet 359 in 1912. An explanatory memoir[1] was published in 1912. As both map and memoir are now out of print it seemed opportune to issue a new edition. This new map has now been prepared and is passing through the press, and as it contains certain important alterations the following brief explanation is offered to show the reasons why these changes have been made.

The geology of this district has long been regarded as containing many unsettled problems. For many years there was great discussion regarding the Lizard rocks. With the publication of the Survey memoir this has in large measure ceased, and the dust of controversy has settled for a time. It is not doubted that many

[1] ' The Geology of the Lizard and Meneage ' (*Mem. Geol. Surv.*), 1912.

points regarding Lizard geology are still far from clear, and some of them are of fundamental importance, but little that is new and relevant has been discovered in that district during the last twenty years and no alterations of importance seem to be necessary in the geological map at the present time.

It is otherwise, however, in the Meneage, for within the last few years evidence has been found that necessitates important changes in the interpretation of the geological structure and the age of the rocks, and the new edition of the map has been modified to give expression to the current views upon the subject.

The whole of the Meneage was surveyed by the late J. B. Hill and he has expressed his opinions not only in the Survey memoir but also in a number of important geological papers. The subdivisions and sequence of the rocks which he finally accepted are as follows: the rocks are given in descending order.

Devonian (including Manaccan conglomerate)
Unconformity
Veryan (Ordovician, probably Caradoc)
Portscatho
Falmouth
Mylor

He recognized on the north of the Lizard boundary a crush zone (Fig. 1) about a mile broad and extending about six miles inland from the east coast. This contained Ordovician quartzite and also various hornblende-schists and mica-schists of uncertain age and origin.

It is not necessary to recapitulate in full Hill's views regarding the geology of this region. They will be found in the Survey memoir. In this place they will be discussed only in so far as concerns the questions on which new light has been thrown, and the reasons for discarding some of his opinions. There is no doubt that Hill's mapping was of a high order of excellence. During recent years both Mr. Dewey and I have gone over some of the ground with his field maps and found them very full and accurate. The changes that have been rendered necessary by the advance of knowledge arise from the interpretation of a series of field exposures of a very obscure and perplexing character which led Hill to certain conclusions, based on the evidence available at the time of his work, but now needing revision in the light of later researches. His maps, however, have served as the basis for subsequent workers and, though superseded, they mark an important stage in the development of our still incomplete and imperfect interpretation of the geology.

Of cardinal importance in Hill's hypothesis were the rocks which he regarded as Devonian. These were typified by certain shales and grits that occur on the west coast near Gunwalloe and on the east coast at Nare Head, on the south side of the mouth of the Helford River. They were well known to contain obscure plant remains, represented by thin dark impressions on their bedding planes, which had never been satisfactorily identified or given names, either

specific or generic. A few doubtful shells, corals, etc., had been collected also near Nare Point, but only provisionally identified, and not certainly from the same beds as contained the plants.

At Nare Point these fossiliferous beds are associated with a conglomerate, well seen in the beach at Menaver. This was interpreted as marking the unconformable base of the Devonian.

The other fixed point of his hypothesis was the white quartzite that occurs in several parts of the Meneage. This quartzite has always been regarded as the same as the Gorran Quartzite which contains fossil brachiopods, trilobites, etc., that establish its age as Ordovician (probably Caradoc). No fossils of importance had been found by Hill in the white quartzite of the Meneage, though in some grey grits obscure brachiopod remains had been obtained that harmonized sufficiently well with the presumption that they were Ordovician. With the quartzite were placed certain pillow lavas, cherts, and sporadic patches of limestone, to make up the Veryan Series, and it was maintained that a similar association occurred in the type area at Veryan and Mevagissey, twenty or thirty miles to the east.

The other rocks in the Meneage and the country to the north of the Helford River were divided into Portscatho, Falmouth and Mylor beds. They took their names from localities in the Falmouth district, where they were first recognized, and they extended in belts from Falmouth in a south-westerly direction across the northern part of the country represented on the Lizard Sheet. Hill regarded these as older than the Veryan and as forming a descending sequence in the order given. His reasons are briefly stated in the Lizard Memoir (p. 27). He found that the Devonian conglomerate rested on and contained Veryan and Portscatho rocks but it was doubtful whether it was in contact with or contained Falmouth and Mylor rocks. Hence presumably the Veryan was the uppermost member of the series. The whole might be relegated to the base of the Ordovician, Llandilo, Arenig or perhaps somewhat lower horizons.

The Hendriksi Beds

The most important advance that has been made in our knowledge of the geology of the Meneage, and indeed of the west of Cornwall generally, during recent years, is the discovery by Miss E. M. Lind Hendriks of fossil plants in certain beds hitherto supposed to be unfossiliferous. These plants have been fully described by Professor Lang[1] of Manchester University, and their anatomical characters and stratigraphical significance have been discussed by him. The most characteristic of these fossils are fragments of wood in which the microscopic structure has been preserved. They are found to belong to the genus *Dadoxylon* and the specific name *Dadoxylon hendriksi* has been given to them. With them occur remains of a more doubtful character which Professor Lang compares

[1] Lang, W. H., 'On fossil wood (Dadoxylon Hendriksi, n.sp.) and other plant remains from the clay-slate of South Cornwall,' *Annals of Botany*, vol. xliii, 1929, p. 663.

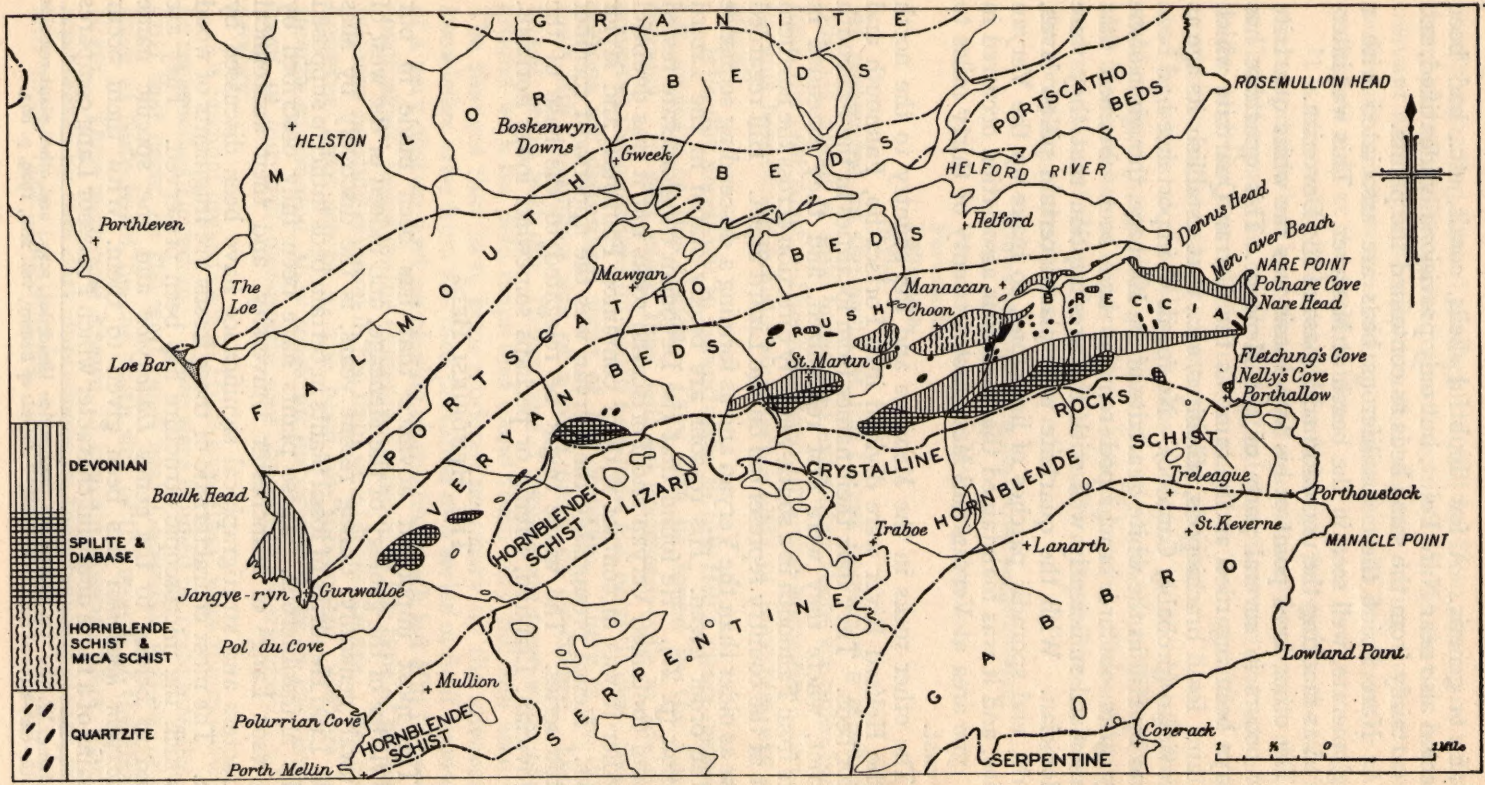


FIG. 1.—*The Geology of the Meneage according to the Geological Survey map, Sheet* 359, 1912.

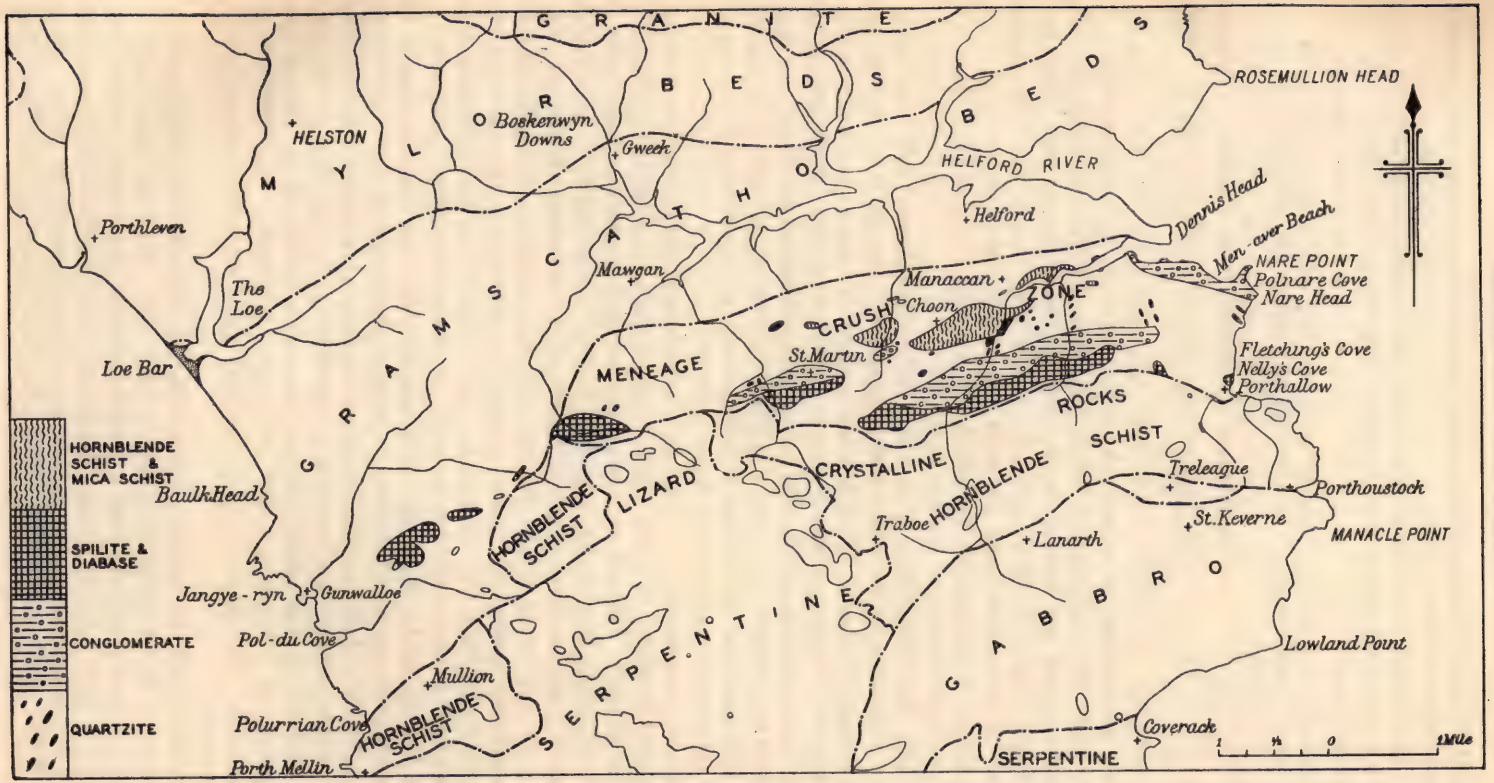


FIG. 2.—*The Geology of the Meneage according to the Geological Survey map, Sheet* 359, 1933.

to *Asteroxylon*, *Thursophyton*, etc., but which are too indefinite for specific determination.

The localities in which these plant beds have been found and the horizon ascribed to them in the 1912 edition of the Lizard map are as follows :—

Manaccan Beds : Nare Head, Polnare Cove, Baulk Head, Jangye Ryn.
Veryan Beds : Polurrian Cove, Poldhu Cove, Gunwalloe Church Cove, Porthallow.
Portscatho Beds : Portscatho Harbour, and other localities not in the Meneage.
Falmouth Beds : Gunwalloe Fishing Cove, Cliff south of the Loe Bar.

It seems impossible to believe that the beds containing these plants are not on or about the same horizon. Consequently it is clear that the lithological characters on which Hill depended in preparing the geological map have proved deceptive. His distinctions between Falmouth, Portscatho, Veryan and Manaccan beds, in these localities at any rate, must have been fallacious, and doubt arises in all the other cases in which he determined the geological horizons on similar grounds.

Miss Hendriks has found the fossil plants in other districts extending from Falmouth to Mevagissey and outside the boundaries of the Lizard Sheet. This region has not been re-examined by the Geological Survey and the deductions which may be drawn from her discoveries in these parts are not at present under discussion. It is hoped that before long she will publish her results and conclusions. In the meantime our object is to explain the reasons for the changes that have been made in the Lizard Sheet.

In the summer of 1932 I spent a month in the Meneage, examining the coast sections and the inland exposures over a considerable part of the district. In the course of that work I was able to confirm all the localities given in the above list (except Porthallow). The plants occur in certain localities where the grits and shales have in large measure preserved their original bedding and are not excessively crushed and contorted. One of my objects was to ascertain whether the beds yielding the Hendriksi flora could be distinguished and separated out as a distinct group. I found that this could not be done ; in fact, undecipherable shreds of what are apparently vegetable tissues can be found in many places where the conditions are not too unfavourable. The conclusion at which I arrived was that in this Sheet the Falmouth, Portscatho and Manaccan beds as established by Hill must be put into one group (Fig. 2) for the purposes of mapping. The Veryan, however, has distinctive characters. The position of the Mylor Beds will be discussed at a later stage.

In country so broken by faults, thrusts and folding as the Meneage it is not possible to make sure that there are no infolds or infaulted outcrops of other horizons among the strata under description. Strictly the term Hendriksi Beds might be reserved for those in which the fossil plants have been proved to occur. For the whole group including those strata which may reasonably be

believed to belong to the same horizon the name Gramscatho Beds has been adopted and employed by Miss Hendriks.[1] This implies that the Portscatho Series is generally typical of the group. In the country to the east it was believed that the Manaccan Beds correspond approximately to the Grampound grits. Both of these strata were regarded as Devonian; both contained a conglomerate which was assumed to mark the base of the Devonian, resting on the Ordovician or older rocks. This possibility is not yet eliminated entirely. The question is an open one and we have adopted a name which is derived from Grampound and Portscatho, which even if ultimately it proves unjustified will mark a stage in the development of opinion on the correlation of the rocks of the South of Cornwall. It will be observed that on the new edition of the Lizard Sheet (Fig. 2) the Gramscatho Series forms a broad band extending from Polurrian and the Loe on the west coast, across the Helford River in an east-north-east direction. Passing south of Falmouth it extends into the Portscatho and Gerrans Bay district, where the Hendriksi Beds are now known to occur, through the researches of Miss Hendriks.

With regard to the age of the Hendriksi Beds we are entirely dependent on the palaeobotanical evidence. The few remains of animals (shells, corals, etc.) that have been found in, or associated with, the plant beds are of little value in this respect. The significance of the plant remains has been very fully discussed by Professor Lang, to whose paper we must refer the reader for fuller details. The most important fossil is the *Dadoxylon*. Similar fossil wood is known from the Upper Devonian, and is not uncommon in the Carboniferous. It is not known, however, at lower horizons, and there is practically nothing about the associated plant remains that suggests a Lower Devonian age for the rocks. That they are Silurian or Ordovician is, to say the least, highly improbable. On the balance of evidence it seems reasonable to believe that they may be Middle Devonian.

This conclusion is revolutionary: and it involves not only the Meneage but also the whole of the South-west of Cornwall. Hitherto it has been generally believed that that area has an anticlinal structure, the Mylor Beds forming the core of the arch, followed outwards and upwards by Falmouth, Portscatho and Veryan, over which the Lower Devonian unconformably overlapped. If these beds are Middle Devonian or Carboniferous (with the exception of the Veryan, in part) the structure is wholly different.

The Mylor Beds

Some reference may be made here to the Mylor Beds, although nothing that is really new has arisen regarding them. Hill, for reasons already stated, regarded them as the oldest beds in the country, with the exception of the Lizard schists. These Mylor

[1] Hendriks, E. M. L., 'The Stratigraphy of South Cornwall,' *Rep. Brit. Assoc.* for 1930, 1931, p. 332.

rocks do not form a large part of the ground represented on the Lizard Sheet and are often so much altered by the contact-action of the Carnmenellis granite that they cannot reasonably be expected to contain well-preserved fossils. There is a good exposure of them, however, on the west coast between Porthleven and the Loe Bar. In this district the bedding is often quite well preserved though there is sometimes much contortion. No fossils, however, have yet been found in the rocks mapped by Hill as Mylor.

Hill has placed on record that he found no fragments of Mylor rocks in the Manaccan conglomerate. He interpreted this to mean that the Mylors were not exposed in the land surface on which the conglomerate was laid down. It might equally mean, of course, that the Mylors were subsequent to the conglomerate and had not yet been deposited. In that case the succession is upwards in a northerly direction, or the reverse of what was postulated by Hill. No certainty can at present be reached on that point. The discovery of fossils in the Mylors, which is quite an open possibility, might satisfactorily settle the doubt.

In the Lizard Sheet the junction between Mylors and Gramscathos on the west coast is covered by the Loe Bar. The inland exposures are inconclusive. There is nothing, however, that seems to make it unlikely that the succession is a continuous one. The lithology of the beds is not strikingly different and they have obviously been subjected to similar degrees of stress and folding. Although Hill had traced this group over a very large extent of country he saw nothing to lead him to believe that its junction with the ' Falmouth ' Beds was marked by an unconformability.

The Menaver Conglomerate

The conglomerate that is exposed in Menaver Beach, on the south side of the entrance to the Helford River is in some respects the most interesting rock of the Meneage. It has been described by all workers on the geology of the district and its importance was clearly recognized by Hill, who made it the foundation on which he built his hypothesis of the sequence of strata in Western Cornwall. The rock is well seen for rather less than half a mile along the shore. It does not form the Nare Point but is seen again in high rough cliffs on Nare Head : from there it extends southwards along the shore for several hundred yards.

The conglomerate mostly shows no signs of bedding (Plate Ib) and in many places it seems to be practically unsheared. The rock varies somewhat in colour, being grey, greenish, or red (when weathered). It has a rather characteristic matrix with small dull yellowish specks, which are grains of weathered felspar or felspathic igneous rocks. In this lie boulders of all sizes. Most of them are an inch to a few inches in diameter, but there are very large boulders consisting mainly of a dark grey hard quartzite or grit. Some of these are two feet or more in length and one or two feet in diameter, and they are very well rounded, as a rule. The variety of pebbles in

A.—FLOATING MASS OF ORDOVICIAN QUARTZITE IN THE MENEAGE CRUSH ZONE, PENARE.

B.—MENAVER CONGLOMERATE, HALAMANA, FLUSHING.

this rock as recognized by inspection of the hand-specimens is extraordinary. Among the commonest are hard white, grey or yellow grits. There are also granite, pegmatite, and vein quartz. Dull greenish pebbles are mostly diabase and other igneous rocks. To these must be added, chert or cherty shale, grey limestone (scarce) and pieces of black shale or phyllite, up to six inches in length but usually less than one inch in thickness. Grey and greenish schists, fine-grained gneisses and granulites and yellow epidiorites also occur, mostly as pebbles of small size.[1] The only rock belonging to the surrounding country that can be clearly identified is the white Ordovician quartzite. It seems well established that Lizard serpentine, gabbro and greenstone do not occur in the conglomerate. They have been much sought for and all observers agree on this point. The absence of the serpentine might be accounted for by its softness, but the Lizard greenstones are very tough rocks, much used for road metal and likely to yield durable pebbles. It has been suggested that the explanation is that the Lizard crystalline masses were not exposed at the surface when the conglomerate was laid down; but alternatively it might be argued that the Lizard rocks are of later date than the deposition of the conglomerate.

The great variety in the size of the pebbles is a striking feature and might suggest a glacial origin for the mass. But none of the pebbles have the blunted shape of glacial boulders; they are not striated, and the matrix does not resemble that of a boulder-clay.

Another point that calls for mention is the occurrence of quite small, well rounded pebbles of soft black shale or slate. How they were preserved in such a tumultuous mass, full of large blocks of hard quartzite, is not easy to comprehend; but it seems unlikely that they can have been transported from any great distance.

It is clear from the particulars given above that the rock is a true conglomerate and not a crush-conglomerate; but in places it is crushed, and moreover there are crush-conglomerates in the district that may resemble it very closely, especially when the true conglomerate has been involved in the crushing.

The Meneage Crush Zone

This belt of broken rocks extends inland from the east coast to near the Lizard road (Fig. 2), having a length of about six miles and a breadth of about a mile and a quarter. It is exposed on the sea cliffs from a little south of Nare Head to the south side of Porthallow Cove. Unfortunately much of this coast is difficult of access and the

[1] Microscopic examination of a number of slides made from this rock proved the following constituents:—

Metamorphic:—phyllite, mica-schist, granulite, mylonite, sheared quartzite, hornblendic ? schists (rare, rotten), ferruginous schists, sheared granites, garnet, epidosite, vein quartz.

Igneous:—granophyre, albite-diabase, hornblendic and epidotic diabase, spilite, keratophyre, quartz-keratophyre, palagonite (?). The keratophyres are often subvariolitic, and belong to types not known in western Cornwall. The spilites are seldom vesicular.

Sedimentary:—grit and greywacke, slate and shale, cherty slate, chert (no limestone).

rocks are so much broken and crushed that their true relations are often doubtful. Parts of the section, however, are sufficiently clear, and frequently there are rocks which can be identified, such as the quartzite, radiolarian cherts and pillow lavas. Many of the little coves, however, are occupied by black or grey shales, broken grits and cherty breccias, to which it is difficult to assign a horizon.

The characteristic of this zone is that everything in it occurs in lenticles or phacoids, elliptical in shape and tapering at each end. Some of these lenticles are of great size. The spilite and conglomerate mass, for example, that passes from Trewothack to Tregidden is about four miles long. The hornblende-schist lenticle of Choon has a length of about a mile. Some of the quartzite lenticles (Plate IA) are about a quarter of a mile in length. These larger masses are embedded in a breccia or sheared mass which consists principally of black or grey shale, with fragments of dark grits, usually a few inches in length, and having the shape of a lance head or a willow leaf. Pieces of quartzite, granophyre, schist, spilite and many other rocks may be found in this breccia, which varies enormously from point to point. It is sometimes incoherent, and breaks up under the hammer, but often it is sufficiently compact and indurated to yield blocks of considerable size, and may then be tough enough to serve as road metal.

The materials of this breccia, both large and small, have a fairly consistent strike, which is practically east and west, or parallel to the extension of the general outcrop and to the Lizard boundary. There are also many indications of a dip, which is towards the south at high angles.

On the 1912 edition of the Lizard Sheet, Hill gave this country a ground colour which represented it as belonging to the Veryan or Ordovician, but he showed the principal outcrops of hornblende-schist, mica-schist, quartzite and spilite by their characteristic colours, and he inserted two large masses of a conglomeratic 'Devonian' which he regarded as resting unconformably on the Veryan. Along the whole belt of broken country he inscribed in large letters the words 'crush breccia.' In going over this ground recently with Hill's six-inch maps I have been much impressed with the care with which he had searched and described all the outcrops. It is obvious, however, from his field notes that he was often at a loss regarding the true nature of the rocks. The crush-breccia often resembles a true conglomerate, and the fragments in the breccia are by no means easy to determine.

The interpretation of this puzzling country which Hill favoured, though he did not regard it as established, was the following. The essential elements of the sequence were the Veryan rocks, quartzite, pillow lavas, radiolarian cherts, a little limestone and much dark shale and grit. Into these there had been injected certain intrusions of basic rock that had been converted by movement during consolidation into fine-grained hornblende-schists. These he regarded as the intrusive edges of the Lizard Complex. The mica-schist

of Manaccan had been produced by the operation of these intrusions on the Ordovician shales. The Devonian grits and conglomerates rested unconformably on the Veryan. Brecciation during the Hercynian movements had reduced the whole series to its present broken condition. The Lizard boundary line was probably a thrust, though he doubted if it was a displacement of great magnitude.

There is no doubt that Hill was profoundly impressed by the close parallel which could be established between the geology of Ballantrae in Scotland and that of the Meneage and Lizard. At Ballantrae we have serpentine, gabbro and granite, sometimes foliated as in the Lizard. There is also a belt of hornblende-schist between the serpentine and the country rocks. The pillow lavas and radiolarian cherts of Ballantrae present a very close resemblance to those of the Meneage. The serpentine and gabbro are believed to be their plutonic representatives. Moreover the age of the Scottish series is Lower Ordovician, which is also the age of the Veryan rocks. Almost every lithological feature of the one district is repeated in the other, and if the Ballantrae country had been cut to pieces by a later series of movements the analogy between the two districts would be still more complete.

The weak points in this correlation are not obvious at first glance: a few of them, however, may be mentioned here. It has been shown that at Fletchings Cove, about half a mile north of Porthallow, there are limestones containing Silurian fossils. These of course might be explained as being a lenticle of newer rocks involved in the great breccia by the late-Carboniferous movements. It is clear that the north edge of the Lizard rocks is a great thrust or fault. It is sharply defined and the metamorphic state of the rocks on each side of it is entirely different. There is no evidence that the Lizard serpentine or schists are intrusive into the Ordovician, as there is at Ballantrae. The absence of Lizard rocks from the Menaver conglomerate cannot be explained if the Lizard rocks are intrusive into the Veryans. In the latter case, also, the 'Devonian' conglomerates near the Lizard boundary should contain Lizard rocks. The hornblende-schists are among the oldest rocks of the Lizard. They are followed by the prolonged series of intrusions, serpentine, gabbro, granite and dykes of many sorts, but none of these has ever been found to cut any rock north of the Lizard margin, though they occur in great numbers to the south of it. The sedimentary rocks of the Lizard district are highly crystalline granulites, mica-schists with andalusite and sillimanite, cordierite-anthophyllite-gneisses and the Treleague Quartzite, all of which are of very different facies from the fossiliferous Veryan.

The interpretation of the Meneage Crush Zone which appears to me to fit the facts at present known in the best manner is that it consists of a vast mass of pre-Cambrian and Palaeozoic rocks containing Lizard schists, Ordovician, Silurian and Devonian (and possibly Carboniferous) driven northwards and broken up by the late-Carboniferous Hercynian movements.

The north edge of the Crush Zone is a well-defined line passing a little south of west from Gillan Harbour to the junction of the Coverack and Lizard roads. To the north of this line are Gramscatho Beds much folded but not intensely brecciated. This line is probably a great thrust or 'sole' on which the breccia has been pushed northwards. Unfortunately it is not well exposed in any of the coast sections, but in the inland country it is often as well defined as the Lizard boundary and its position has been laid down on the maps with sufficient correctness by Hill.

A remarkable feature of the Meneage Crush Zone is that it is clearly divisible into three or four bands. The northern band contains many lentictes of hornblende-schist and mica-schist, and also the Manaccan granophyre. The next band contains many outcrops of Ordovician quartzite. These are well seen on the coast below Penare (Plate IA) and they have been quarried in the fields in many places inland. To the south of this band, on the coast-line, occur the Silurian limestones of Fletchings Cove. The southern band contains the pillow lavas, cherts and the 'Devonian' conglomerate. The Hendriksi flora has been found at Porthallow immediately north of the Lizard boundary.

I regard it as probable that this banded structure of the Meneage Crush Zone is the reflection of an original stratigraphical sequence. At the base we have the crystalline schists (of the Lizard): on these rested the Ordovician rocks: next came the fossiliferous Silurian: then the pillow lavas and cherts with the conglomerate and, in close association, the Hendriksi Beds. These are the recognizable elements of the sequence. What other rocks occur in the breccias cannot at present be determined. Evidently there was much shale, grit and greywacke which may have been Ordovician, Silurian, Devonian, or even Carboniferous, but it is now torn into shreds. The whole pile may have been several thousand feet thick. Though disrupted and displaced it still retains traces of the original succession.

On this hypothesis the pillow lavas and cherts of Porthallow and Mullion are not necessarily of Ordovician age as has hitherto been assumed. I know of no evidence which proves that they are Ordovician; pillow lavas and radiolarian cherts are now proved to occur in all the principal Palaeozoic formations, and also in the pre-Cambrian. It is interesting to note that Hill thought, in 1906, that the Meneage pillow lavas might be Devonian. Miss Hendriks in the brief synopsis of her views on the succession, published in 1931,[1] has placed some of the pillow lavas of South Cornwall in the Upper Devonian, above the Gramscatho Beds, and others in the Middle Gramscatho. There may quite well have been several series of pillow lavas in the Meneage; many of the types of spilitic rocks in the Menaver conglomerate are not known *in situ* in South Cornwall at the present day.

[1] *Op. cit.*

The outcrop of the Meneage Crush Zone dies out to the west near the Lizard road. Its exact termination has not been closely defined and the lines drawn on the map must be regarded as approximations. They correspond closely with the disappearance of the characteristic quartzite blocks. On the west coast the Hendriksi Beds extend from Polurrian to the Loe Bar. The line on the 1912 map, which Hill drew as the eastern boundary of the Devonian in that district, is no longer satisfactory. Two explanations may be offered for the disappearance of the Ordovician rocks in this quarter. One of these is that the northern and the southern boundary thrusts of the Meneage Crush Zone may have come together and fused. The other, and the more probable, is that the Crush Zone is faulted out by two powerful faults, one in Pol-du Cove and one in Polurrian Cove. These throw down to south and bring the over-riding Lizard schists down against Hendriksi Beds, cutting out the outcrop of the Meneage breccias altogether. The northern margin of the Lizard rocks between Belossack and Polurrian Cove is probably defined by a series of normal faults with considerable displacements.

There are two points regarding which the evidence at present to hand is by no means conclusive. The first of these is the relation of the conglomerate to the plant-bearing beds. On the west coast the Hendriksi Beds are excellently exposed over a distance of three and a half miles, but the conglomerate has not been found among them. On the east coast the Hendriksi flora has been found at Polnare Cove, just south of Nare Point, but these beds are separated from the Nare Head conglomerate on the south by a fault. Neither at Menaver nor at Flushing in Gillan Creek, two typical localities for the conglomerate, do the accompanying dark shales and grits yield the plant remains. At Porthallow the plants are found in a small isolated outcrop of gritty beds and the conglomerate is not seen in the exposures on the shore. It is therefore a matter of inference from their proximity at Nare Point that the conglomerate and the Hendriksi Beds belong to the same series.

A similar difficulty exists as regards the pillow lavas. Like the conglomerates they are not seen in the long shore section of the Hendriksi Beds on the west coast. Neither do they occur at Flushing, Menaver or Nare Point. At Porthallow they occupy the north side of the Cove, while the Hendriksi Beds occur on the south, and the exposures are separated by a gravel beach a hundred yards long. In the inland exposures the pillow lavas are accompanied by a conglomerate which is quite probably on or about the same horizon as the Nare Point and Menaver conglomerate. But nowhere, as yet, have the pillow lavas been found in close and indubitably original connexion with Hendriksi Beds.

It should be remembered that the Menaver conglomerate is full of fragments of spilitic rocks: some of these resemble the pillow lavas of Mullion Island, Porthallow and Tregidden. Many, however,

belong to types not represented at these localities. The Menaver conglomerate is not really a tuff, though it seems quite probable that volcanic activity was going on during the deposition of the conglomerate. This would not easily account, however, for some of the fragments of hypabyssal spilitic rocks such as albite-diabase and epidotic diabase.

Still, it seems probable that these three groups are part of one series, as their outcrops undoubtedly hang together in a general way. If this be admitted the question remains unsettled whether the conglomerate and pillow lava belong to the bottom or to the top of the Hendriksi Beds. I have not found any clear indications of the solution of that problem. The conglomerate contains many boulders of grit and greywacke but there is nothing about them sufficiently distinctive to prove that they are derived from the Gramscathos or the Mylors.

II.—CONTRIBUTIONS TO THE GEOLOGY OF THE KENT COALFIELD

(I). THE SEQUENCE AND STRUCTURE OF THE KENT COALFIELD

BY

H. G. DINES, A.R.S.M., A.M.INST.C.E.

Plates II to IV ; Text-figures 1-12.

BORINGS AND SHAFTS

THE following account of the Kent Coalfield is based largely upon the records of the borings and shafts listed in Table A. Many of these records were supplied by Mr. E. O. Forster Brown, and others were obtained through the courtesy of Messrs. Pearson and Dorman Long, Ltd. Copies of the private reports to the companies concerned, by E. A. Newell Arber and Dr. H. Bolton on the Coal Measures proved in fifteen of the boreholes have also been made accessible by this company. Much information relating to the individual collieries and to general conditions in the field has been freely given by officials at the various collieries recently visited, especially by Mr. G. C. H. Nasmyth, late of Betteshanger Colliery, who had spent some time considering the available records, with a view to selecting suitable sites for further borings and shafts.

The coalfield is proved by the borings and shafts to be confined to that part of Kent which lies south of the latitude of Ramsgate and east of the longitude of Sturry.[1] In all cases, with the exception of Adisham, the bore records consist of nothing more detailed than borers' logs, and are not generally as full as could be desired for correlation purposes. They give a fair idea of the strata passed through, however, and together with the information obtained by the Geological Survey from a few sinkings, yield sufficient information for a broad classification of the coal-bearing beds.

Of the 34 borings and 5 shafts given in Table A, five borings are just outside the coalfield (*viz.* Brabourne, Harmansole, Herne, Herne Bay and Reculvers) and serve to prove its limits. Coal Measures are proved in 33 cases (including the 5 shafts) and 14 of the borings which prove Coal Measures pass into Carboniferous Limestone, while two (*viz.* Rushbourne and Chislet Park) prove the absence of Carboniferous Limestone beneath the Coal Measures in north-western corner of the field. One boring, situated beyond the

[1] The extension of the coalfield beneath the sea and its possible connection with the Pas de Calais Coalfield are not dealt with here.

TABLE A. TABULATED DATA RELATING TO THE BORING AND

Borings and Shafts (1)	Date of Sinking: Commenced (2)	Date of Sinking: Finished (3)	O.D. level of surface. Marked ? where approximate (4)	Coal Measures where proved. Depth in feet to: top (5)	Coal Measures where proved. Depth in feet to: bottom (6)
RECULVER	1914	1914	17	...	...
HERNE BAY	1913	1913	100	...	...
HERNE OR BLEAN	...	...	130	...	...
RUSHBOURNE	1912	1913	73	1135	1550
CHITTY	1912	1913	5	?870	?
CHISLET PARK (Bore)	1912	1913	14‡	1036	1604
HOADES	1913	1913	?120	1092	1246
CHISLET SHAFTS	1914	1918	68	1096	1470
STODMARSH	1910	1911	87	1065	2140
WALMESTONE	1908	1913	74	1076	2276
FLEET OR ASH OR COOPER STREET	1913	1913	?20	1089	1860
RICHBOROUGH OR EBBSFLEET ...	1910	1912	10	1057	1163
TRAPHAM	1910	1911	59	1125	2776
WOODNESBOROUGH	1908	1909	51	1075	2621
MATTICE HILL	1909	1912	11	975	2051
LYDDEN MARSH	1912	1914	11	952	1959
HARMANSOLE	1913	1914	?220	None	
BISHOPSBOURNE OR BOURNE ...	1913	1914	176	1313	3170
ADISHAM	1922	1923	133	1211	3236
GOODNESTONE	1906	1907	136	1188	2905
BETTESHANGER (Bore)	1913	1913	95	1100	2911
BETTESHANGER SHAFTS	1924	1927	75	981	2426
FREDVILLE	1905	1907	259	1372	1835
SNOWDOWN SHAFTS	1909	1925	242	1321	3020
BARFRESTONE	1907	1912	193	1205	3327
TILMANSTONE SHAFTS	1906†	1930	215	1165	3458
RIPPLE	1911	1911	68	882	3270
ROPERSOLE	1898	1899	400	1582	2129
WALDERSHARE	1905	1907	335	1394	2863
MAYDENSOLE	1910	1911	253	1194	3760
OXNEY	1910	1912	136	998	3704
STONEHALL	1911	1912	221	1290	3691
ELHAM	1914	1915	275	1598	2239
ELLINGE	1900	1902	460	1660	1800
CHILTON	1912	1913	159	1100	?3060
BERE FARM	1913	1915	396	1361	3008
BRABOURNE	1897	1898	215	...	...
SHAKESPEARE SHAFT (Brady Bore)	1886*	1890	50	1157	2330
FOLKESTONE	1915	1916	113	1487	3400

* Date of Bore. Second Shaft 1912. †No. 2 Shaft 1907, No. 3 Shaft 1910. Deepened to Millyard Seam, 1930. ‡ Though some records give the surface O.D. level of this bore as 50 ft., as shown in Group 5, Plate IV, the true level is believed to be 14 ft.

NOTE.—The figure in Column 6 refers to the bottom of the section when Carboniferous Limestone or older rocks are not proved. The depths are from surface.

SHAFT SECTIONS OF THE KENT COALFIELD AREA

Carboniferous Limestone proved to—Depth in feet (7)	Older Palaeozoic rocks penetrated to—Depth in feet (8)	Fossils Recorded from Coal Measures: Plants (9)	Fossils Recorded from Coal Measures: Molluscs (10)	Analyses of Coals available for most of the seams in sections marked (11)	Remarks (12)
...	1029	...	...	...	
...	1964	...	...	...	
...	1187	...	...	...	
...	2491	...	...	...	Older Palaeozoics were proved, but not Carboniferous Limestone.
?	? 2015	...	...	...	Sub-Mesozoic rocks struck at 870 ft. may be of Carboniferous age or older.
...	2901	...	...	...	Older Palaeozoics proved beneath Coal Measures.
...	...	...	...	...	
...	...	S	...	*	C.M. proved to 1489 ft. in borehole in West Drift
2263	...	A	B	*	
2285	...	A	B	*	
1961	...	A	B	*	
1389	...	...	...	...	
3220	...	...	B	*	
2633	...	A	B	*	
2075	...	A	B	*	
2027	...	K	...	*	
1275	1730	...	...	...	Mesozoic rocks rest on Carboniferous Limestone at 1249 ft.
3235	...	A	...	*	
3261	...	...	...	*	
...	...	A	B	*	
2930	...	...	...	*	
...	...	S	S	*	
...	...	A	B	*	
...	...	S	S	*	
...	...	A	B	*	
...	...	S A	S	*	Including bore in bottom.
3317	...	A	B	*	
...	...	...	...	...	
...	...	A	...	*	
...	...	A	B	*	
3739	...	A	B	*	
...	...	A	B	*	
2346	...	K	...	*	
...	...	...	...	...	
...	...	...	...	*	
...	...	K	...	*	
...	2004	...	...	...	
...	...	...	...	*	
...	...	K	...	...	

NOTE.—The figure in Column 7 refers to the bottom of the section when Older Palaeozoic rocks are not proved. The letters in columns 9 and 10 refer to the recorders thus :— A = Arber, B = Bolton, K = Kidston, S = Geological Survey. The dates of sinking were obtained from E. O. Forster Brown, Report of Coal Industry Commission, 1919, A. E. Ritchie, ' The Kent Coalfield,' 1920, M. Burr, *Colliery Guardian*, vol. cvi, 1913, and elsewhere.

western margin of the coalfield (*viz.* Harmansole), penetrates Carboniferous Limestone immediately below the Mesozoic rocks, and another to the north of the field (*viz.* Chitty), on passing through Mesozoic strata, enters sandstones, shales, etc., which, from the log records, are of indeterminate age and may be older than Carboniferous.

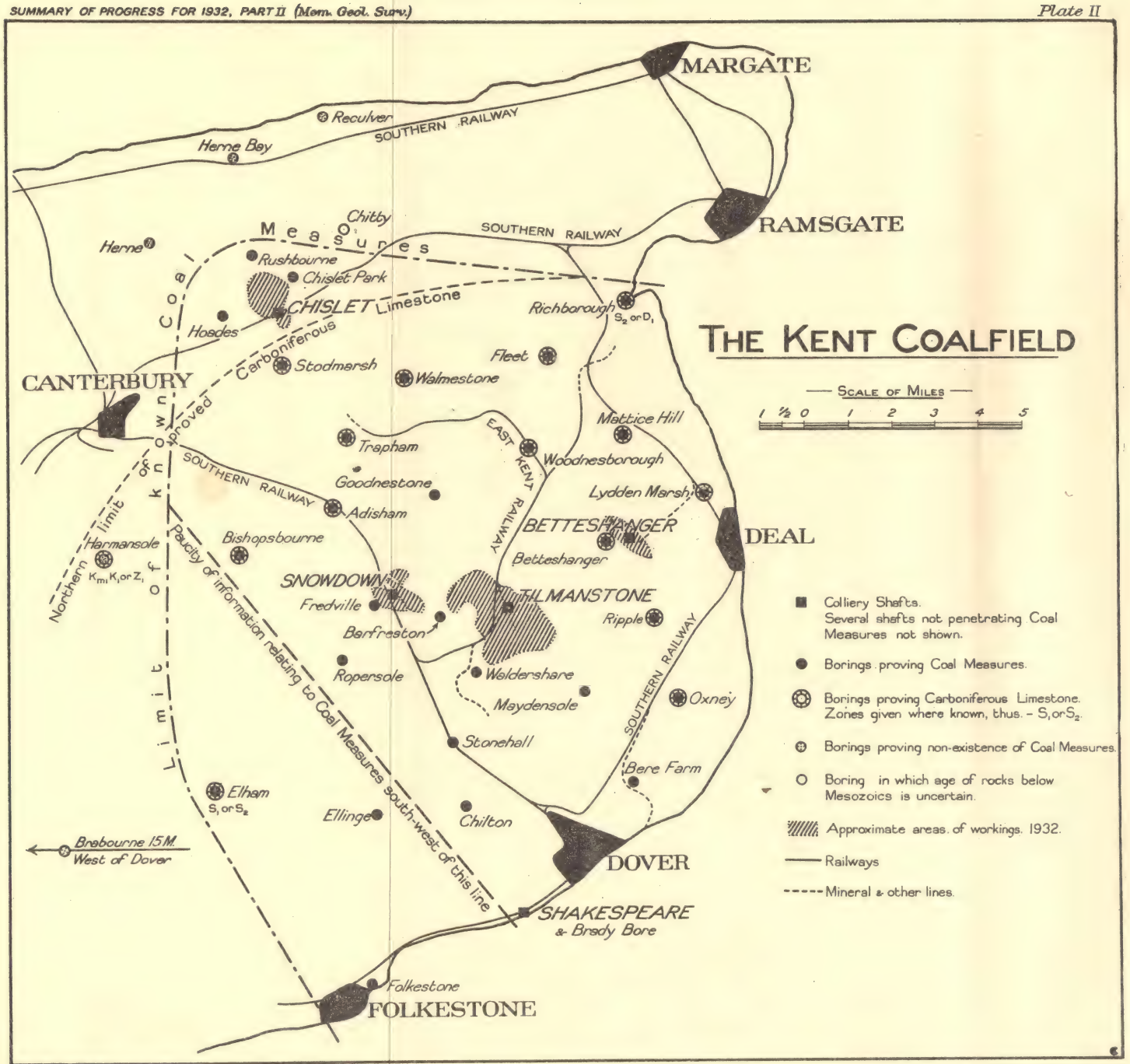
The distribution of the borings throughout the coalfield is shown in Plate II, from which it will be seen that those which prove Carboniferous Limestone beneath Coal Measures, excepting Elham, lie north of a line passing through Shakespeare Colliery and the Bishopsbourne bore. All the more important sections are in this northern area, while outside it the Folkestone, Elham and Ellinge bores do little more than prove the extension of Coal Measures to the south. The borings and shafts within the northern area are fairly evenly distributed, being, on the average, about $2\frac{1}{4}$ miles apart, or situated one in every 5 square miles of country. They serve to give a sound generalized section of this part of the field. The distance apart of the bores and shafts is, however, too large for satisfactory correlation of some of the individual seams, though certain of the more persistent and easily recognized seams can be correlated with a fair degree of certainty.

The records show, on comparison, a fairly uniform sequence of sedimentation of Coal Measures throughout the field, and certain horizons appear to be well defined. The Millyard[1] Seam of Snowdown Colliery (or 'F' Seam of Betteshanger Colliery), for instance, is proved over the whole of that part of the field in which its horizon is present (Fig. 5). The Beresford Seam, near the top of the Coal Measures, occupies a small area near the centre of the field (Fig. 4) and is remarkably constant in thickness throughout the workings of both Tilmanstone and Snowdown collieries, and is identifiable in a number of bores to the south-east. On the other hand, many of the seams are impersistent and can only be identified here and there. The group of coals at Betteshanger Colliery between 2100 and 2300 ft. below surface (known as 'G,' 'H' and 'I' seams) varies considerably throughout the field, though there are frequently one or more workable seams in this part of the sequence.

There are several comparatively large and important parts of the field which still remain unproved, notably east and west of Trapham and north of Walmestone.

In addition to the collieries at present working and Shakespeare Colliery, shafts were commenced in other localities, but in all cases the enterprises were abandoned before or during the Great War, before the shafts had reached Coal Measures. These were known as Wingham, Woodnesborough, Guilford and Stonehall collieries (see pp. 42, 43.) There are also boreholes within the area of the Kent Coalfield which were put down solely for the purpose of proving the extension of the iron-ore deposit in the Corallian beds around Dover. The sites are at Lower Standen, Abbotscliff and Farthingloe.

[1] Often spelt 'Milyard.'



(623) P.S. 1992 1739 850. 6/33. Lp 521. C & R Ltd

These, as well as the Ottinge bore, which was sunk to find coal, but did not penetrate the Coal Measures, are not dealt with in this report.[1]

Stratigraphy

The stratigraphy of the coalfield here described is based upon the assumption that the correlations of the various sections are correct. The relative values of the correlations are discussed later (pp. 27 to 31).

(a) **Structure.**—North of the latitude of Dover the floor of the coalfield is a basin with its maximum depth, of 3850 ft. below O.D. (computed), near Waldershare. The basin is elongated somewhat in a direction north-west and south-east.[2] The floor rises in all directions from around Waldershare and is at about —1100 ft. O.D. along the northern margin of the field (Figs. 2 and 3).

The floor of the basin consists mainly of Carboniferous Limestone, upon which the Coal Measures rest unconformably, apparently overstepping it to rest on older rocks in the area around Chislet Colliery. In nearly all records of the Carboniferous Limestone penetrated there has been evidence that its surface is weathered, indicating a non-sequence.

The upper surface of the Coal Measures is marked by another plane of unconformity, the Coal Measures forming a floor upon which rest the Mesozoic rocks. This plane is gently undulating and has a slight tilt towards the south-west, being at less than —800 ft. O.D. around Deal, and over —1300 ft. O.D. at Folkestone (Figs. 1 and 3).

The Coal Measures themselves are folded into synclinal form, and the various geological horizons throughout their thickness are roughly parallel with the floor of the basin. Even the Beresford Seam, near the top of the formation, is folded in this manner (*cf.* Figs. 2 and 4), which is proof that folding, in the main, post-dated the deposition of the coal-bearing strata, although there is evidence that it was in progress during their deposition.

The southern rim of the basin appears to rise southwards towards the area between Shakespeare Colliery and the Elham bore, but the Coal Measures are proved to a depth of more than 400 ft. deeper at Folkestone than the inferred depth of the base of the Coal Measures at Shakespeare Colliery. Accepting this inferred depth, the floor of the Coal Measures must be ridged between Dover and Folkestone, and the bore at the latter locality must lie within a second basin. The position of this supposed ridge is in alignment with the anticlinal axis that separates the Carboniferous basins of the Pas de Calais and the Bas Boulonnais.

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[1] For descriptions of the Mesozoic rocks penetrated in these and other borings see 'Mesozoic Rocks of Kent Coal Explorations' (*Mem. Geol. Surv.*), 1911, 'Concealed Mesozoic Rocks in Kent' (*Mem. Geol. Surv.*), 1923, and other publications of the Geological Survey, also E. O. Forster Brown, *Proc. Inst. C. E.*, vol. ccxv, 1922-23, pp. 27-144.

[2] The form of the basin has been discussed by E. A. N. Arber, *Trans. Inst. Min. E.*, vol. xlvii, 1913-14, p. 689, Sir A. Strahan, in discussion on a paper by H. Bolton, *op. cit.*, vol. l, 1915-16, p. 74, and H. A. Baker, *Iron and Coal Trades Review*, vol. ci, 1920, p. 785.

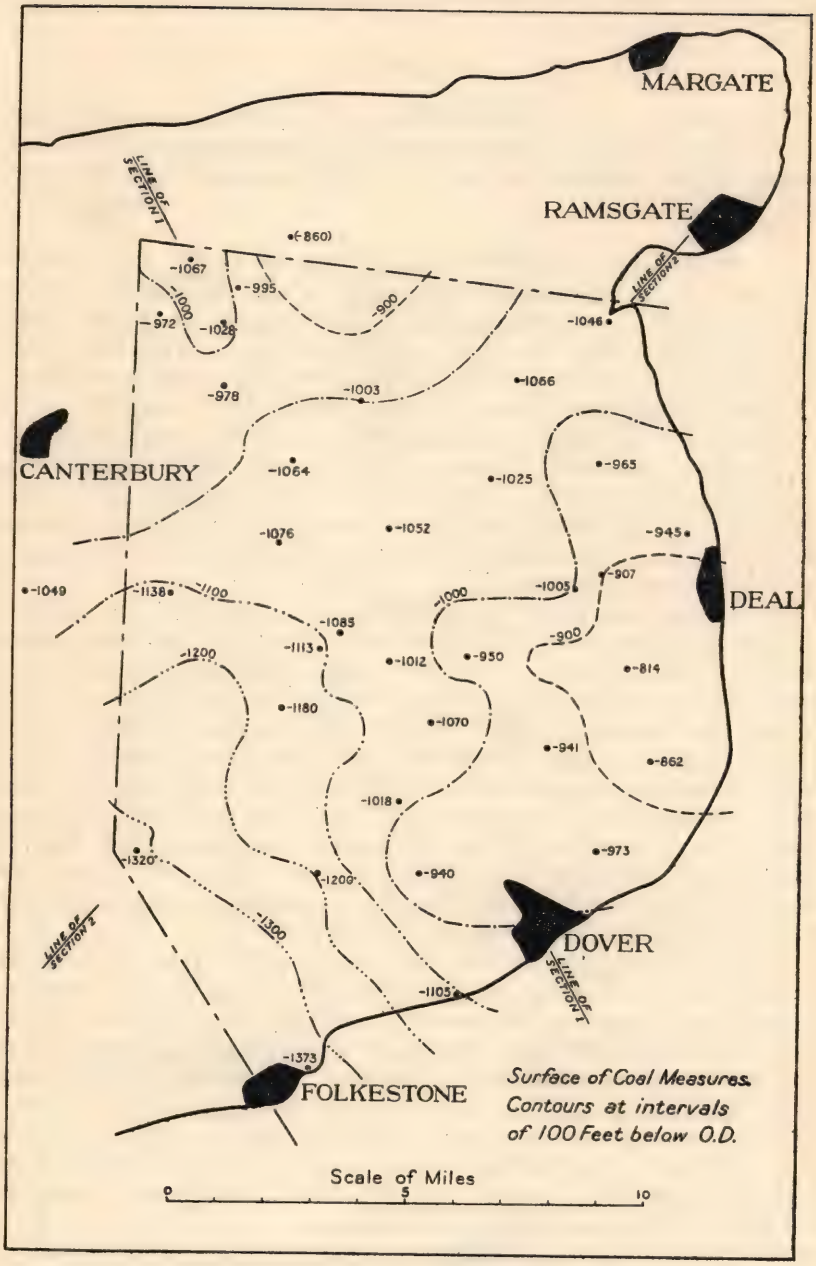

FIG. 1.—*Contours of the sub-Mesozoic surface.*

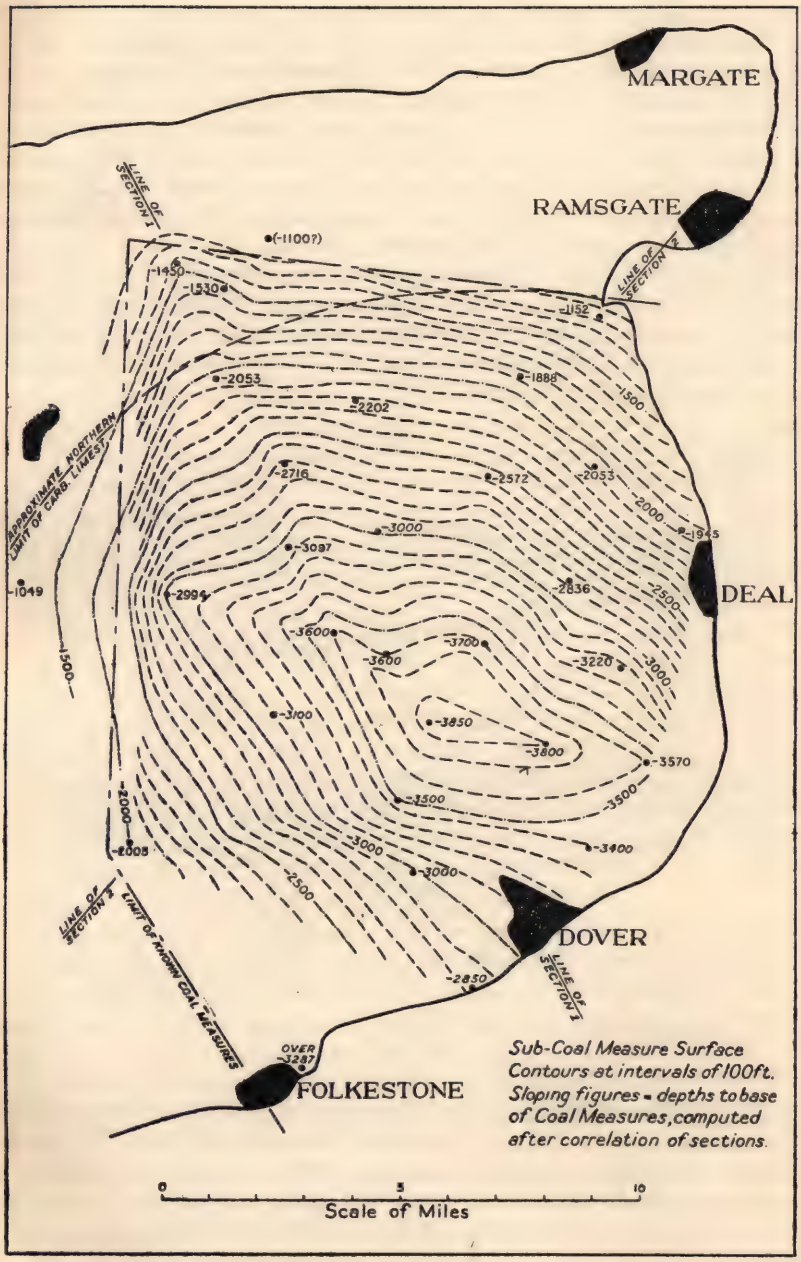

FIG. 2.—*Contours of the sub-Coal Measures surface.*

There is little evidence upon which to determine the ultimate limits of the field, or the nature of its boundaries. Eastward and southward the extent of the Coal Measures is quite unknown. The Harmansole bore, south of Canterbury, is the most westerly which proves Carboniferous rocks. The Carboniferous Limestone in this locality belongs to a low horizon (Lower Limestone Shales) and may represent the bevelled edge of the Carboniferous strata. On the other hand, the rise of the floor of the basin from --3000 ft. O.D. at Bishopsbourne to —1000 ft. at Harmansole is more sudden than in any other part of the basin and suggests that the western margin of the field may possibly be marked by a line of faulting. The northern limit of the field is not determined within close limits, but it is apparent that the Coal Measures overstep the Carboniferous Limestone on to older rocks, to be planed off to a feather edge beneath the unconformable Mesozoic rocks a little to the north of the present known position (Fig. 3, Sect. 1).

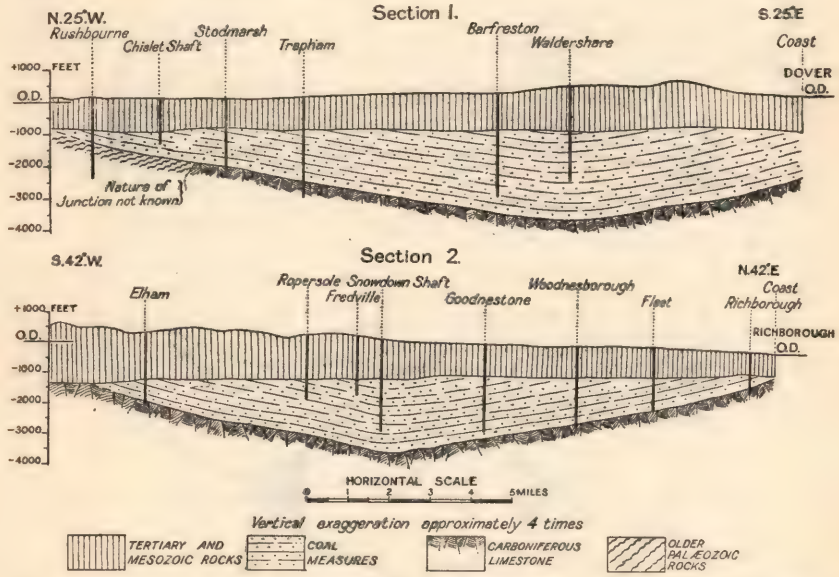

FIG. 3.—*Horizontal sections across the Kent Coalfield. (For positions of lines of section see Fig. 1 or Fig. 2.)*

(b) Sedimentation.—The sequence of sedimentation of the Coal Measures appears to be constant throughout the field. Of the 2800 ft. of measures present the lowest 700 ft. or so consist mainly of shales and binds with coals, some of which are thick. It is in this lowest lithological division that Chislet and Betteshanger collieries are working. Above this the formation consists mainly of sandstone with subordinate binds and few, mostly impersistent, coal seams. Where the highest beds are present, near the centre of the basin, there is a tendency for the sandstones to give way upward to shales and binds, again with coals, amongst which is the Beresford Seam.

The group of coals in the bottom or shale division extends throughout the field, though it is frequently impossible to identify individual seams in the various sections. Fireclays are sometimes present without coals, and the seams range in thickness from a few inches to 9 ft. or more, but individual seams fluctuate considerably in thickness and often split. Deposition, therefore, appears to have taken place on a gently undulating and slowly subsiding surface, resulting in variations in thicknesses of the coal seams, accompanied by local areas of contemporaneous erosion as well as by splitting of seams. Sandstones are rare in this lower division and generally of no great thickness, though near its upper part sandstones develop in the north-western part of the area as shown by the sections at Bishopsbourne, Adisham, Trapham, Stodmarsh, Chislet Colliery, Chislet Park, Hoades and Rushbourne (see Plates III and IV).

Near the base of the upper or sandstone division is the Millyard or 'F' Seam. This is separated from the lower shale division, in most sections, by about 100 ft. of sandstone, and the beds overlying it, for a thickness of 200 ft. or so, consist of binds with a few subordinate sandstones, several coals, generally thin, and fireclays (see Fig. 6). This sequence is remarkably constant throughout the field and represents a horizon of uniform sedimentation over the whole area.

The vertical interval between the Millyard Seam and the base of the Coal Measures varies. The seam is approximately 250 ft. nearer the Carboniferous Limestone around Fleet and Lydden Marsh than around Bishopsbourne. From this it may be inferred that the thickness of the underlying sediments increases towards the centre of the basin, and consequently that folding had commenced early in the history of the deposition of the Coal Measures, but since the depth of the Carboniferous Limestone is not proved in any of the borings on the south side of the basin, in which the Millyard Seam is present, this can only be an assumption.

The upper or sandstone division persists for about 2000 ft. above the Millyard Seam. In all sections binds are associated with the sandstone, but coals and fireclays are less frequent than in the lower shaly division, although there are some fairly persistent seams near the middle, *e.g.* the 5 ft. 2 in. coal at 2375 ft. in the Waldershare bore, and the Snowdown Hard, which is a 3 ft. 0 in. split seam at 2245 ft. in Snowdown Colliery and a 2 ft. 8 in. split seam at 2275 ft. in Tilmanstone Colliery.

In the top part of the sandstone division, near the centre of the basin, where the shales develop at the expense of the sandstones, there is a series of coals which includes the Beresford Seam. This group is about 2200 ft. above the base of the Coal Measures, but it is folded in a similar manner to the lowest beds. There is, however, a slight diminution in thickness of the strata between the Beresford and the Millyard seams outwards from the centre of the basin, again suggesting that folding was in progress during deposition.

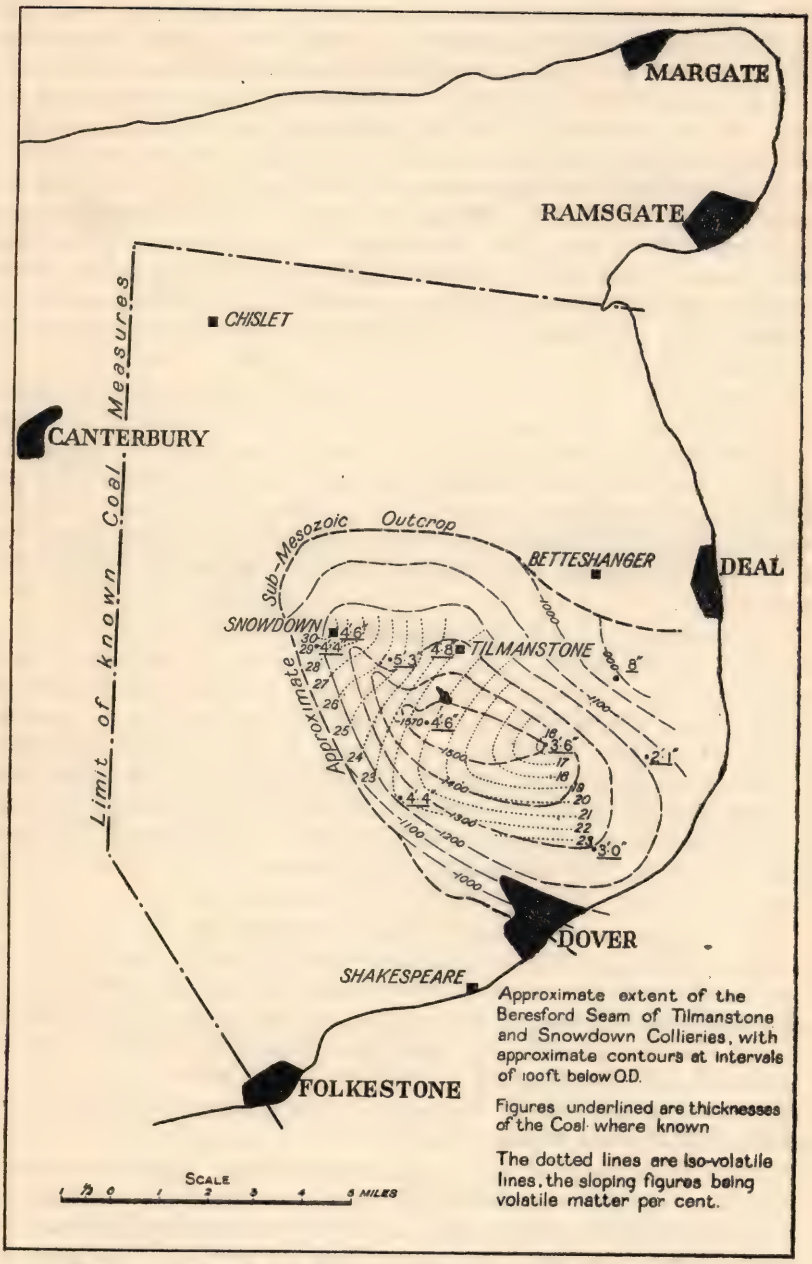

FIG. 4.—*Contours and Iso-volatile lines on the Beresford Seam.*

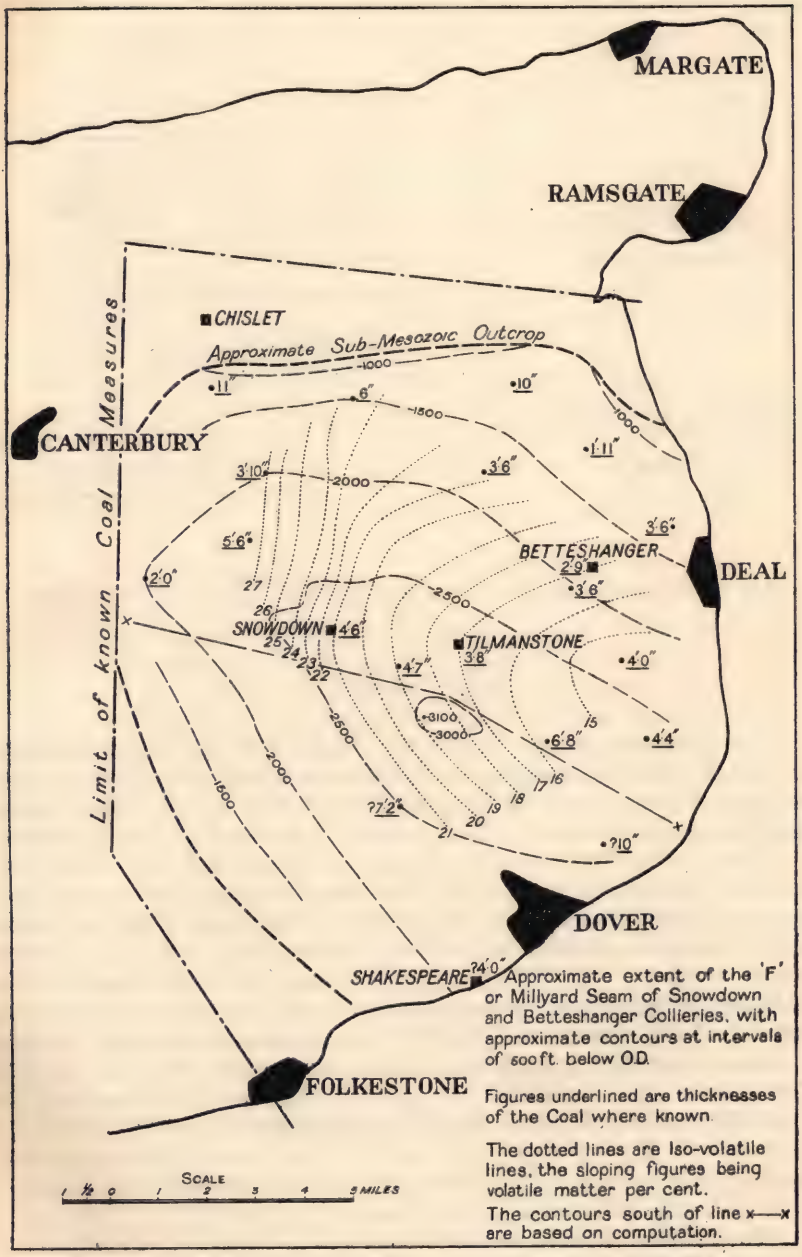
MARGATE
RAMSGATE
CHISLET
Approximate Sub-Mesozoic Outcrop
CANTERBURY
Limit of known Coal Measures
BETTESHANGER
DEAL
SNOWDOWN
TILMANSTONE
DOVER
SHAKESPEARE
FOLKESTONE
SCALE
MILES
Approximate extent of the 'F' or Millyard Seam of Snowdown and Betteshanger Collieries, with approximate contours at intervals of 100ft. below O.D.
Figures underlined are thicknesses of the Coal where known.
The dotted lines are Iso-volatile lines, the sloping figures being volatile matter per cent.
The contours south of line x—x are based on computation.

FIG. 5.—*Contours and Iso-volatile lines on the Millyard or 'F' Seam.*

The sections show an average of 29 coal seams, of which 13 belong to the lower or shale division and the remainder to the upper or sandstone division of the measures.

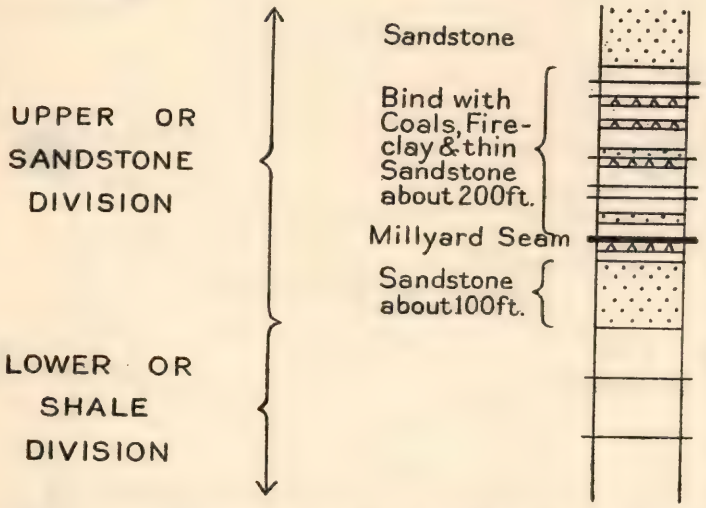

FIG. 6.—*Generalized section at the horizon of the Millyard or 'F' Seam.*

PALAEONTOLOGY

The information yielded by the fossil flora and fauna collected in the coalfield is meagre, and although broad classifications are fairly well established the fossils have proved to be of little value as aids in correlation or in the identification of individual seams.

The freshwater lamellibranchs collected by the Geological Survey have been identified by Professor Trueman, who states that it is not possible to draw any reliable conclusions from the shells so far collected, though it is fairly certain that both the *Anthracomya phillipsi* and the *A. tenuis* zones are represented. The division between these zones occurs a little above the Millyard Seam, but the upward extension of the *A. tenuis* zone is not known.

According to reports by Bolton on some of the borings, *Carbonicola* and *Naiadites* are present in the lowest part of the Coal Measures, and from this it has been inferred by Prof. Trueman that the *A. pulchra* zone is present.[1] The lowest 300 ft., approximately, may belong to this zone, which leaves about 600 ft. of strata to the *A. phillipsi* zone.

The marine fossils, according to Dr. Stubblefield, afford no evidence enabling correlation of the marine horizons to be made with marine bands in other coalfields. Goniatites have been found

[1] 'A suggested Correlation of the Coal Measures of England and Wales,' *Proc. South Wales Inst. of Eng.*, vol. xlix, 1933.

only in fragmentary condition. Marine fossils, however, fix a well-marked horizon between 100 and 200 ft. below the Millyard Seam in several sections. This is within the zone of *A. phillipsi*.[1]

It has been established by Dr. Crookall[2] upon plant evidence that :—

(1) The bottom 650 ft. or so of the Coal Measures, *i.e.* the lower or shale division, belongs to a fairly high part of the Yorkian Stage.

(2) The passage from Yorkian to Staffordian Stage occurs about 150 ft. below the Millyard Seam.

(3) The plants present at the horizon of the Beresford Seam indicate the Keele (or Farrington) Group, *i.e.* the lower division of the Radstockian Stage. The exact position of the base of this division has not been determined but it is believed to be 100 ft. or so below the Beresford Seam.

The beds at Chislet Colliery have yielded a flora indicative of a high part of the Yorkian Stage, and they appear to belong to the horizon below the ' F ' (or Millyard) Seam at Betteshanger.

The classifications of the Coal Measures of Kent are shown diagrammatically in Fig. 7.

Correlation of the Sections

The remarks in the foregoing parts of this report are based upon the correlation of the various borehole and shaft sections as shown in the Groups of Correlated Sections (Plates III and IV).[3] The correlations are based upon the comparison of the sequences of deposition that are recorded in each case. All the available evidence has been used in endeavouring to identify the various seams and horizons in each of the sections. The groups of sections, as shown on the key map, are taken as nearly as possible in lines crossing the field in directions north-west to south-east or north-east to south-west, in order to bring out the structure. Most of the sections, especially those which show the full thickness of the Coal Measures, appear to present little difficulty, but other records yield insufficient information to be of value for correlation.

The various boreholes which present uncertain information or which require special comment are dealt with below. They are taken in order, as far as possible, from north to south ; the sites are shown on Plate II.

Herne (or Blean, or Thorndon Wood), Herne Bay (or Beltinge) and Reculver Bores.

These all lie to the north of the coalfield and penetrate older Palaeozoic rocks beneath the Mesozoic sediments.[4]

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[1] See ' Notes on the Fauna of the Coal Measures of Kent,' ' Summary of Progress ' for 1932, Part ii (*Mem. Geol. Surv.*) 1933, pp. 71-82.

[2] See ' The Fossil Flora of the Kent Coalfield,' ' Summary of Progress ' for 1932, Part ii (*Mem. Geol. Surv.*), 1933, pp. 44-70.

[3] The Adisham bore section shown in Groups 1 and 4 has inadvertently been plotted 200 ft. higher than its true level relative to Ordnance Datum.

[4] See H. A. Baker, *Iron and Coal Trades Review*, vol. ci, 1920, p. 788.

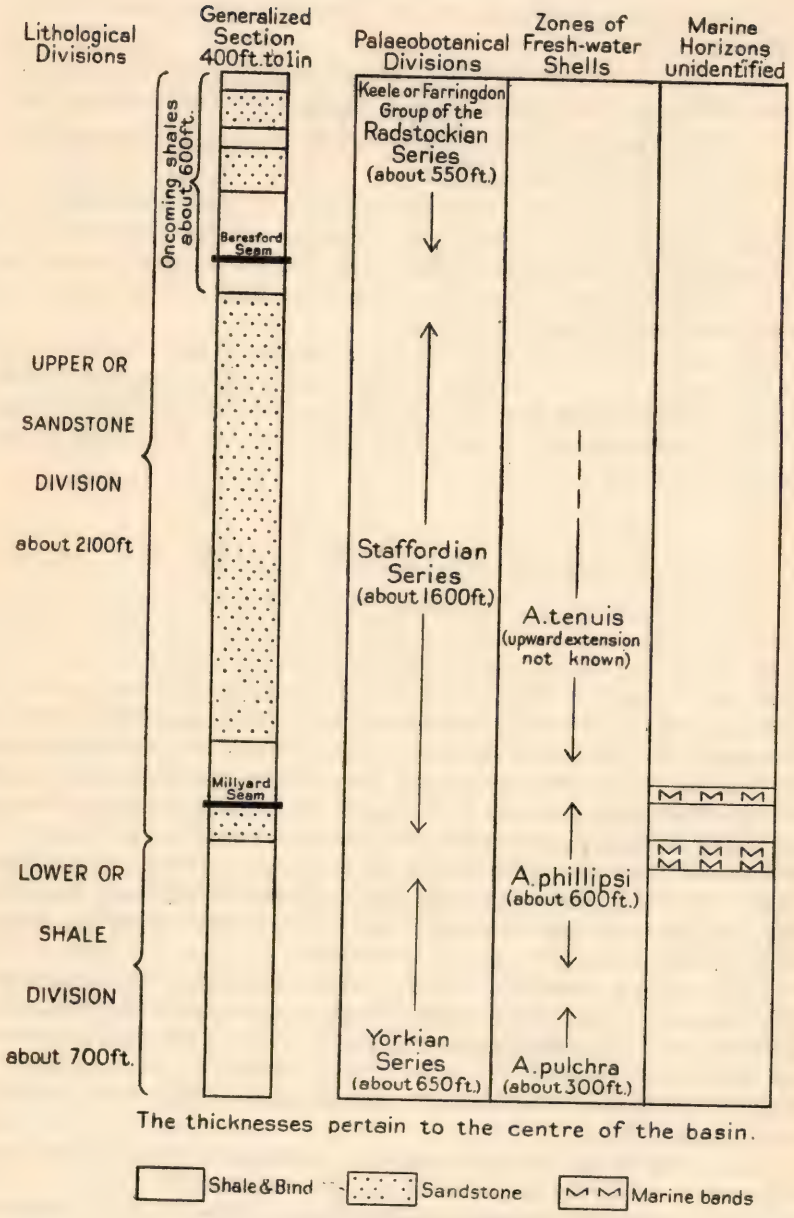

FIG. 7.—*Classification of the Coal Measures of Kent.*

Chitty Bore.

The only known published account of this section is as follows[1] :—

	Thickness Ft.	Depth Ft.
Mesozoic rocks	... 874	874
Coal Measures	... 256	1130
Carboniferous Limestone	... 885	2015

The borer's log, however, gives the following section, which has been generalized :—

	Thickness Ft. In.	Depth Ft. In.	
Coal Measures entered		870 0	
Blue shale	4 0	874 0	
Sandstone	135 6	1009 6	
Shale and bind	110 6	1120 0	
Carboniferous Limestone	10 0	1130 0	
Bind with some sandstone	685 0	1815 0	
Basalt with quartz	8 0	1823 0	
Conglomerate	45 0	1868 0	
Bind	70 0	1938 0	
Conglomerate	2 0	1940 0	
Bind	18 5	1958 5	
Conglomerate	56 7	2015 0	Bottom

In the absence of fossils and of coal seams or fireclays there is no evidence to show that the above rocks are of Carboniferous age. 'Blue bind' and conglomerate of ? Silurian age were encountered below the Mesozoic strata both in the Herne Bay and in the Reculver borings, and similar rocks were met with below Coal Measures in Rushbourne and Chislet Park bores. The limestone referred to as 'Carboniferous Limestone' in the Chitty bore is only 10 ft. thick and might well be of pre-Carboniferous age. This boring is therefore regarded as not proving Carboniferous rocks.

Rushbourne and Chislet Park Bores (*see Group* 5).

Both of these sections show that the Coal Measures of this area rest upon rocks which are probably older than the Carboniferous Limestone. The generalized sections are as follows :—

Rushbourne	Thickness Ft.	Depth Ft.
Coal Measures entered		1135
Coal Measures ...	269	1404
Sandstone and shale ...	160	1564
Basalt with quartz veins and shale	146	1710
Sandstone	63	1773
Shale	104	1877
Fireclay	3	1880
Shale with basalt ...	8	1888
Sandy shale and bind	89	1977
Red and green sandstone	58	2035
Sandstone and shale ...	229	2264
Conglomerate with thin fireclays near top ...	188	2452
Red & green sandstone	23	2475
Red and green conglomerate ...	15½	2490½ Bottom

Chislet Park	Thickness Ft.	Depth Ft.
Coal Measures entered		1036
Coal Measures	568	1604
White rock	13	1617
Sandstone and shale ...	684	2301
Bind	187	2488
Conglomerate with bind	128	2616
Bind	35	2651
Red and green sandstone	33	2684
Conglomerate	25	2709
Red and green sandstone	145	2854
Conglomerate	47	2901 Bottom

[1] Baker, H. A., *op. cit.*

The recording of 'fireclays' in the Rushbourne bore does not necessarily indicate that the rocks are of Coal Measures age.

Hoades Bore (*Group* 4) *and Chislet Shaft* (*Group* 5).

Both of these sections prove the presence of productive Coal Measures, but the rocks underlying the Coal Measures were not penetrated.

Richborough (*or Ebbsfleet*) *Bore* (*Group* 1).

This section proves attenuation of the Coal Measures in the north-eastern corner of the field, and also the presence of Carboniferous Limestone beneath them. The Carboniferous Limestone appears to belong to the horizon at the base of the D_1 Zone or top of the S_2 Zone, which implies that the uppermost zones D_1 and D_2 (usually representing about 1000 ft. of strata) are missing. The surface of the Carboniferous Limestone was piped and showed signs of having been eroded.[1]

Harmansole Bore (*Plate IV*).

This proves that the Mesozoic rocks rest directly upon the Lower Limestone Shales division of the Carboniferous Limestone, the zone present[2] being apparently the Km, the K_1 or the Z. The thickness of strata between the Z_1 Zone and the top of the S_2 Zone (which is present at Richborough) is about 2000 ft. in the Bristol district and in South Wales.

Stonehall Bore (*Group* 3).

Below the 7 ft. 2 in. coal at 2782 ft. in this boring there is, according to the records, an unusual number of thick coals, several of the thicknesses being repeated exactly. The bore may have passed through an area of reversed faulting or overfolding, causing the repetition of the seams, but as it is impossible to infer in what way the disturbance, if any, has affected the beds, the bore record below 2800 ft. is not considered in the correlation.

Chilton Bore (*Group* 3).

The sandstones, shales, binds, etc., are not differentiated in the records of this boring. It seems probable that the coals in the lower part (below 2650 ft.) belong to the group of coals usually present in the lower or shale division of the Coal Measures, but beyond this correlation is not possible.

Ellinge Bore (*Plate IV*).

This proves nothing beyond the presence of Coal Measures to a thickness of 140 ft.

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[1] See A. Strahan, 'Summary of Progress' for 1911 (*Mem. Geol. Surv.*), 1912, pp. 70-72. For the horizons of Carboniferous Limestone present at Elham, see J. Pringle, 'Summary of Progress' for 1927, Part ii (*Mem. Geol. Surv.*), 1928, p. 80, and *op. cit.* for 1916, 1917, p. 38. H. Bolton gives the zones present at Trapham and Stodmarsh respectively as C and S_2 or D_1, *Trans. Inst. Min. Eng.*, vol. xlix, 1915, p. 54.

[2] See 'The Concealed Mesozoic Rocks in Kent' (*Mem. Geol. Surv.*), 1923, pp. 119, 120.

Folkestone Bore (*Plate IV*).

This boring proves the existence of Coal Measures, with some coals near the top. The section, however, is unlike any other section of similar depth, and correlation is impossible. Coal seams do not occur below 2500 ft., although the boring is 3400 ft. deep. Coal Measures plants occur down to 3100 ft., but none appears to have been identified in the bottom 300 ft. of the bore.

Shakespeare Colliery and Brady Bore[1] (*Group* 3).

Although the section is situated some 5 miles south of the nearest sections that lie within the better known part of the field, it is tentatively suggested that the 4-ft. seam at 2225 ft. in the Brady bore may be correlated with the Millyard or 'F' Seam, although it is at a higher level than the Millyard Seam in any of the sections to the north. This is admittedly speculative, but is supported by the fact that there is a general rise to the southwards of the beds south of Waldershare, observable in the Stonehall and Bere Farm bores, and even in the Chilton bore if the lower coal seams are accepted as belonging to the lower or shale division of the Coal Measures. Moreover, in a number of the sections there is a fair agreement in the sequence of deposition of strata above the Millyard Seam with that in the Brady bore above the 4-ft. seam.

Other Bores.

The suggested correlations of the borings are shown in Plates III and IV. As already stated, the several seams which occur in the lower or shale division, some of which are thick, cannot be identified with certainty from section to section. The correlations in these lower beds must be regarded as tentative. The Betteshanger Colliery is working coals in this group known as the 'H' and 'I' seams, (3 ft. 8 in. at 2150 ft. and 2 ft. 8 in. + 1 ft. at 2223 ft. respectively) and it would appear from the correlations that the 5-ft. seam at Chislet Colliery, which is now being exploited, is at a slightly lower horizon than the 'I' Seam of Betteshanger. In the sandstone division, except for the Millyard or 'F' Seam and the Beresford Seam, coals are not generally persistent. The Snowdown Hard Seam (1 ft. + 2 ft. at 2235 ft. in Snowdown Shaft) can be identified in places, but even this occasionally is absent, as at Waldershare, Maydensole, Ripple, Oxney and Bere Farm, *i.e.* in the area at and south-east of the deepest part of the basin, as well as at Woodnesborough.

In the shales near the top of the Coal Measures the Beresford Seam of Tilmanstone and Snowdown collieries is usually identifiable, but the seams above this are again very variable.

[1] No. 1 Shaft was sunk on the site of the bore, but did not reach so great a depth.

Characters of the Coal Measures

(a) Lithology.

The non-carbonaceous sediments of the Coal Measures consist of a series of sandstones and shales. The former predominate except in the bottom 700 ft. of the strata where they are rare. The shales or binds are grey, blue-grey or nearly black and range from soft soapy shales through hard mudstones to sandy shales. Fireclays or seat-earths are usually present beneath the coals, and often occur where coals are absent. In a few cases they overlie seams. Bands of ironstone nodules are frequently present in the shales. The existence of fireclays without coals, and also of pebbles of coal in some of the sandstones, is evidence of contemporaneous erosion at intervals throughout the deposition of the measures. The coals belong to the bituminous class. They are laminated beds consisting mainly of fusain and clarain in layers which seldom exceed an inch in thickness. The coals are fragile, and, when worked, produce a high proportion of 'fines.' In some seams, however, there are harder bands of coal which with careful handling can be worked in large lumps. These bands are often a foot or so thick and appear to be composed of durain to a large extent.

Dr. Crookall[1] has pointed out in his account of friable coals that the friability of the Kent coals is due in part to the frequent recurrence of fusain bands and in part to the closely spaced cleat. The frequently recurring layers of fusain and clarain are indications that during the formation of a seam the plant-remains were accumulated sometimes above and sometimes beneath water. There are also variations in the plant parts which go to make up the coals of the different laminae.

(b) Disturbances of the Coal Seams.

Disturbances are of common occurrence in the coal seams. They may be due (a) to post-Coal Measures tectonic movements producing faults or folds in the coal seams or (b) to various causes acting during the formation of the seams.

As far as can be ascertained from the correlation of the sections, the beds of the basin dip gently, the slopes not exceeding 1 in 12 or 13 (about 4°)[2], and there do not appear to be any faults of large throw. In all the workings, however, faults have been encountered. The apparent trend in each case is nearly north-west and south-east, parallel to the main axis of the basin. The faults at Chislet Colliery trend in this direction. Two faults in the northern part of the workings strike about W.10° N. and N.25° W. respectively, and the ground near their intersection is crushed so much as to render the coal unworkable. The throw of the former of these is about 20 ft. to the

[1] '*Fuel in Sci. and Prac.*', vol. xii, 1933, pp. 276-279.

[2] Locally the dips are higher, for the Millyard Seam south-west of the shafts at Snowdown Colliery dips 1 in 10 to the north-east and the 'H' Seam north-west of the shafts at Bettes-hanger Colliery dips 1 in 9 to the south-west.

north-east at its maximum. A fault encountered in the west drift trends almost north-west and has a downthrow apparently to the south-west. It appears to continue into the workings south of the shaft. The amount of throw is uncertain; an incline driven down from the main 'No. 5' Seam, struck a seam of similar characters at 160 ft. below on the farther side of the fault, but it is not certain whether this was the same seam (see Dr. Crookall's report on the palaeobotany[1]).

In Snowdown Colliery, on the Beresford Seam, a fault with a throw of 60 ft. to the north-east passes about 120 yds. south-west of the shafts and continues across the worked area, diminishing in magnitude to 29 ft. A fault parallel to the above, with a throw of 50 ft. to the south-west, also occurs on this seam. This appears to pass about 150 yds. north of the shafts. The ground directly below these on the Millyard Seam is traversed by a number of faults with throws of various amounts and directions, the largest being 65 ft. to the north-east. The colliery is situated on the major axis of the basin, the beds dipping generally towards the shafts. The larger faults in the Beresford Seam apparently pass to the south of the workings in Tilmanstone Colliery.

In Tilmanstone Colliery faults extend across the area worked. The largest throw (of 60 ft.) is to the north-west of the shafts. This fault downthrows south-west and passes about 400 yds. south of the shafts. It splits into a number of faults throwing in various directions, from 12 to 20 ft., but trending always south-east. About 400 yds. north of the shafts is another which throws 21 ft. to the north-east. This colliery is also situated on the main axis of folding and the beds rise both north-east and south-west at gradients up to 1 in 20, forming a trough, the axis of which runs north-west and south-east, about half a mile south of the shafts.

The largest fault in Betteshanger Colliery is met with in a heading driven south-west from about the middle of the main west drift, or about 700 yds. west-north-west of the shafts (Fig. 12). The heading has not been driven far enough through the fault to prove the coal beyond, but the throw appears to be to the south-west. A mass of coal, lenticular in section, occurs over the seam near the fault plane, and at first sight appears to be due to the faulting. It is, however, probably a continuation of a similar mass seen in the end of the west drift, and shown in the diagram given below (p. 35). The seams in Betteshanger Colliery dip to the south-west.

Rolls in the floors of seams are of common occurrence, especially in the lower seams (*i.e.* Millyard Seam of Snowdown Colliery, 'H' and 'I' seams of Betteshanger Colliery and 'No. 5' Seam of Chislet Colliery). These can only be regarded as having been formed during or immediately after the period of deposition. Like the faults they nearly all trend north-west and south-east, and are evidence in support of the assumption that, though the main folding of the basin is due to movement that followed the deposition of the

[1] 'The Fossil Flora of the Kent Coalfield,' 'Summary of Progress' for 1932, Part ii (*Mem. Geol. Surv.*), 1933, p. 49.

Coal Measures, the process of folding commenced with, and continued during their formation. Among the other phenomena that belong to the depositional period is the occurrence of what appear to be sudden thickenings of a seam. These can sometimes be traced for considerable distances, and generally run close to a belt of nips, or areas of thin coal. The thick coal is probably due to coal having been shifted from the areas of thin coal, possibly by strong floods, and stranded on other parts of the seam before being buried by the overlying sediments.

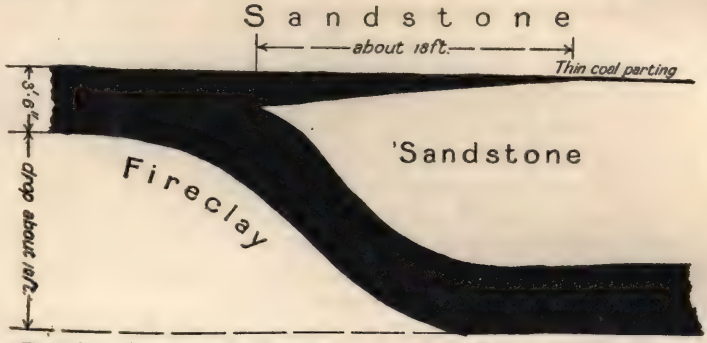


FIG. 8.—*An unusual disturbance on No. 5 Seam, Chislet Colliery.*

In the 'No. 5' Seam of Chislet Colliery rolls occur in the area north of the shaft, and are, in places, so close together as to render the working of the coal unprofitable. They consist of sudden rises in the floor, at the expense of the coal, the lower laminations of which appear to abut against the hump while the higher ones pass straight over. The roof also is unaffected. Gradual reductions in thickness due to variations in the quantity of coal matter deposited are a more common cause of thin coal in this seam. These do not follow the structural directions like the rolls.

An unusual form of contemporary disturbance in the seam is shown in Fig. 8. This is apparently due to contemporaneous buckling of the seam, after which deposition of coal continued for a time, while the depressed area became levelled off with sand. Other indications of contemporaneous movements occur in this seam, such as apparent disturbances of the coal while both floor and roof remain regular, suggesting re-sorting of the coal material.

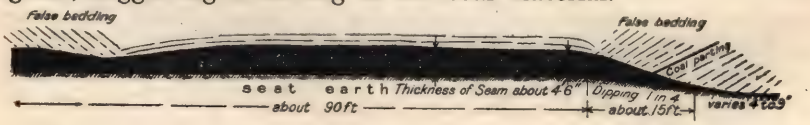


FIG. 9.—*A thinning of the Millyard Seam, Snowdown Colliery.*

At Snowdown Colliery, sudden thinnings occur in the Millyard Seam. The diagram (Fig. 9) shows one obviously due to disturbances during deposition and not to tectonic movement. The Beresford Seam, apart from small changes in thickness and in the distribution of dirt partings, is nearly uniform in thickness here, as it is also at Tilmanstone Colliery.

FIG. 10.—*A thickening of 'H' Seam, Betteshanger Colliery.*

In the 'H' Seam at Betteshanger Colliery there are rolls in the floor trending north-westward. They cross the main west drift about 700 yds. west of the shafts. A thickening of the seam to 9 ft. about 550 yds. from the shafts, along the main east drift, is apparently due to transportation of coal matter as described above. The thickened portion trends north-west and extends across the workings, being followed to the north-east by a thinning of the seam from the normal 3 ft. 6 in. to 2 ft. or less. The sandstone above the disturbance, so far as can be seen in the drift, is bedded as shown in the sketch (Fig. 10). A similar overlying mass of coal occurs in the end of the main west drift, but in this case it is separated from the seam by a parting of sandstone (Fig. 11).

FIG. 11.—*Section at end of Main West Drift, Betteshanger Colliery.*

Another mass of coal overlying the seam is present in the faulted area met with in the heading running south-westward from near the middle of the main west drift, referred to earlier. The heading and the incline down the fault plane expose the section shown in Fig. 12. The fold near the fault plane, both in the seam and in the overlying mass, is probably the result of disturbance during deposition, the fault produced by post-Coal Measures tectonic movement coinciding by chance with the position of the fold. The coal is much crushed, near the fault, both in the overlying mass and in the seam. Rolls occur in the floor of the 'I' Seam, but little development has yet been done on this level.

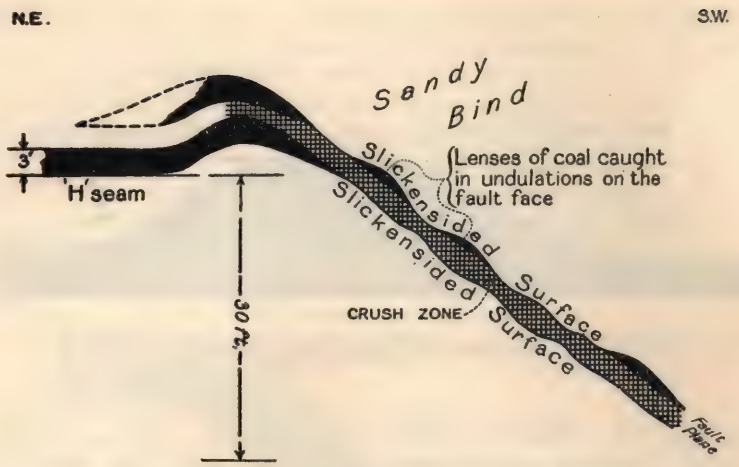


FIG. 12.—*Disturbance and faulting, Betteshanger Colliery.*

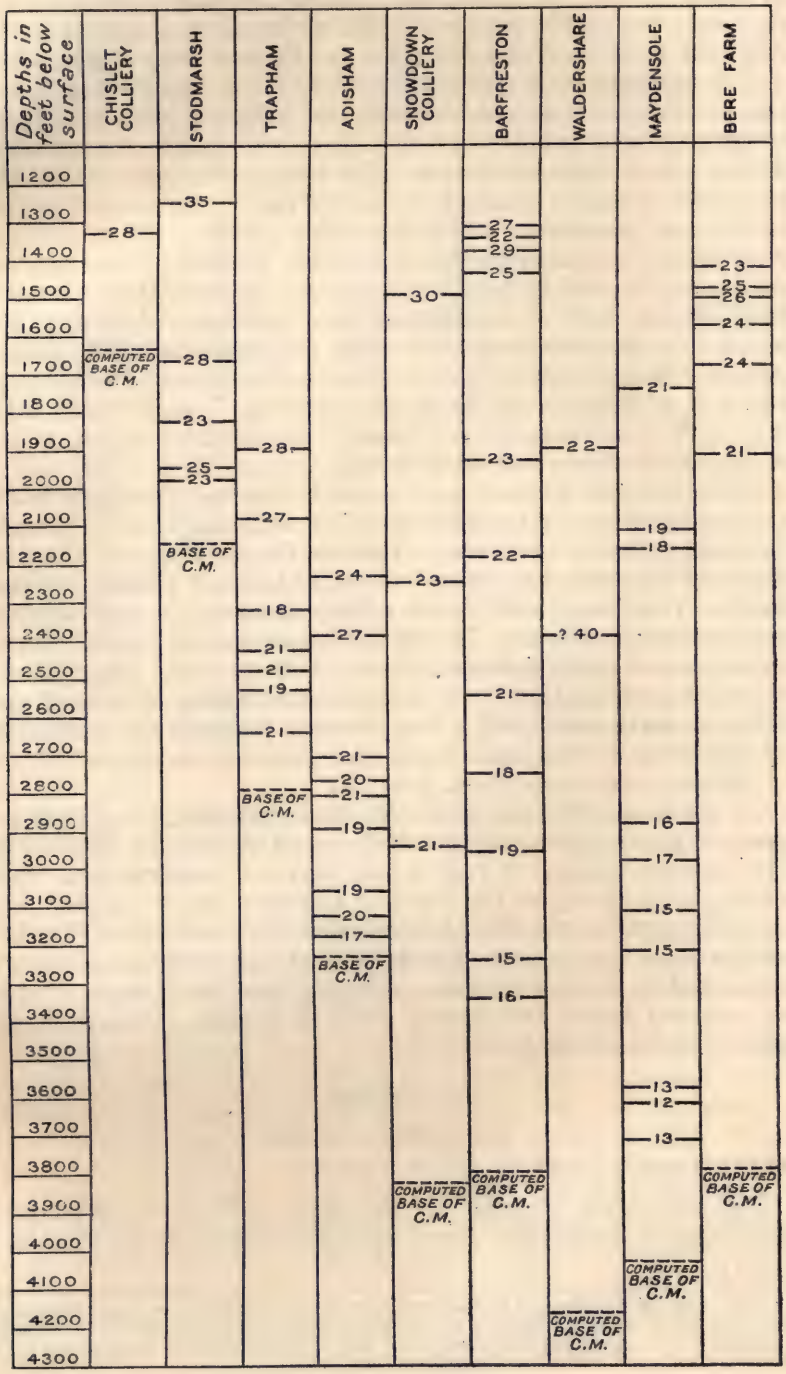
VOLATILE CONTENTS

Records of analyses of many of the coal seams met with in the boreholes and shafts are available. These give the fixed carbon, volatile matter and ash present in the seams, expressed as percentages. The volatile content of the coals varies from place to place apparently according to some law dependent upon conditions under which the seam exists or has existed in the past. The figures giving the percentage of volatile matter show a regularity in change in value, both laterally for individual seams, and vertically in the Coal Measures as a whole.

The coals, spread over a vertical thickness of about 2800 ft. of strata, show a considerable vertical variation in volatile content, the values decreasing with increase in depth. Examples are given in Table B which shows the volatile values for seams in certain of the sections. It will be seen that, though the decrease in volatile matter with increase in depth is a general rule, there are occasional seams which give a higher value than the seams above or below them. Curve charts showing the volatile matter plotted against the depths of the seams do not appear to reveal more than the fact that there is a general falling off of volatile matter in depth. The occasional high values are not confined to any one horizon or depth. They may be due, in some cases, to analytical discrepancies, possibly caused by the fact that a sample obtained from a borehole was not truly representative of the seam.

Although the volatile matter decreases in depth, the lowest values for a particular seam are not confined to the areas where that seam is deepest. In Fig. 5 are shown the iso-volatile lines on the Millyard or 'F' Seam, and a comparison of these with the contours of the seam shows that the minimum of volatile content does not occur

TABLE B. THE VOLATILE VALUES OF SEAMS IN CERTAIN SECTIONS OF THE KENT COALFIELD.



near the maximum of depth of the seam.[1] There is a general increase of volatile values to the westwards from around Oxney. The axis of curvature of the iso-volatile lines courses roughly north-west and south-east, or nearly parallel to the major axis of folding of the seam, but is situated about 2 miles to the north-east of the latter.

The analyses of the Beresford Seam appear to show a similar state of affairs to that which exists in the Millyard Seam (see Fig. 4), but there is not a sufficient number of analyses available from which to draw any definite conclusion. The volatile contents of the other seams also appear to conform to the Millyard Seam in distribution, but it is not possible to verify this owing partly to the uncertainty of correlation of many of the seams and partly to the paucity of analyses. The coal of the 'No. 5' Seam of Chislet Colliery carries about 28 per cent. of volatiles, while the values for what is presumed to be the same seam in borings at Walmestone (3 ft. 5 in. at 1910 ft.), Woodnesborough (4 ft. 0 in. at 2242 ft.) and Betteshanger (4 ft. 6 in. at 2567 ft.) are 20.12, 14.01 and 14.67 respectively. The seam at Woodnesborough is between two seams of higher values, namely 20.53 above and 16.30 below.

That there is a general north-westerly increase in volatile values at all depths is shown in Table B. The sections given in this table are situated on the same line as those in Group 4 (Plate IV) of the Groups of Correlated Sections except that Chislet Colliery replaces Hoades. They are therefore on a line crossing the coalfield from north-west to south-east. The figures are the percentages of volatile matter present in the seams at the depths indicated. They show a general decrease in depth and also a general increase from south-east (right) to north-west (left). This increase towards the north-west is also shown by the iso-volatile lines on both the Beresford and the Millyard seams (see Figs. 4 and 5).

As far as can be seen from the data available, there does not appear to be any phenomenon which would explain the distribution of the volatile values. A view is held that the volatiles are, to some extent, dependent upon the depth of the seam below surface. This theory does not agree with the conditions in Kent to-day, but it is possible that the present distribution of the volatile values was determined by a cover of strata overlying the Coal Measures, which was removed before the present cover of Jurassic, Cretaceous and Tertiary rocks was laid down.

Collieries

(a) Active Collieries

Chislet Colliery Ltd.

The shafts are situated on the south side of the road from Canterbury to Ramsgate, about 2½ miles north-east by east from Sturry.

[1] Similar results are obtained by comparison of the iso-volatile lines with the iso-pachyte lines of the strata above the Millyard Seam. The thickness of strata above O.D. is so small, as compared with that below O.D. down to the Millyard Seam that the arrangement of the contours of the seam and of the iso-pachyte lines are very similar.

Sinking was commenced in 1914, and No. 9 Seam (4 ft. at 1436 ft.)[1] was reached in August 1918. Headings were driven a short distance on this seam both east and west, but as the floor was soft and the roof poor, development was abandoned. A thin seam above the main seam on the west side of the shaft may have been the cause of the roof trouble, but the headings were not driven far enough to prove whether conditions changed beyond. A new landing was made in the shaft at 1350 ft. level and development commenced on 'No. 5' Seam (5 ft. at 1350 ft.) which has been worked continuously since. This seam averages 4 ft. 2 in. in thickness. The roof on the east and north-east of the workings is bind, but on the west and south-west it is a hard grey sandstone. Rolls occur in the floor in places to the north of the shaft and irregular areas of thin coal are often met with, but otherwise the seam maintains a fairly constant thickness. The fireclay floor is soft and rises in the headings and haulage ways; trouble from this cause being rather more marked in the workings in this seam than in seams worked at other collieries in Kent.

The 'No. 5' Seam has been worked in a westerly direction as far as a fault trending roughly north-west. A borehole was put down in the main west drift beyond the fault which proved several thin coals, and a 4 ft. 6 in. seam at about 145 ft. below the level of the drift. A cross-measures drift was then driven to meet the new seam. In thickness, this is comparable with 'No. 5' Seam east of the fault, and the colliery officials are of the opinion that it is the same seam. The sequence of deposition as exposed in the cross-measures drift cannot be definitely matched with any part of the shaft section, but Dr. Crookall has collected a few fossil plants from the roof of the new seam which are also found in the roof of 'No. 5' Seam.

The output from Chislet Colliery is about 9,000 tons per week. The volatile content of the coal is relatively high, being between 27 and 28 per cent.

Snowdown Colliery (Messrs. Pearson & Dorman Long Ltd.)

The shafts are situated east of the railway and south of the road, a quarter of a mile south-west of Holt Street, and 7¼ miles south-east of Canterbury.

Sinking commenced early in 1909 and the Beresford Seam was struck in January 1913. In 1914 the shafts were deepened to the Snowdown Hard Seam, and in 1915 sinking was recommenced in one of the shafts and the Millyard Seam was struck in 1919. Work of an exploratory nature continued in the Beresford Seam pending the opening up of one of the lower seams. In 1924 there was a change in ownership, the colliery being acquired by Messrs. Pearson and Dorman Long, Ltd. The work of sinking the remaining shaft was undertaken by the Company with a view to opening out the Millyard Seam at 2950 feet. In the meantime the whole of the

[1] In the descriptions of the collieries the figures given after a seam mentioned by its local name refer to its thickness and depth in the shaft section.

surface equipment and arrangements were entirely reconstructed and modernized to cope with large scale production when developments were completed. The colliery commenced production from the Millyard Seam in 1927 and since that time there has been a steady increase in output until at the present time the colliery has reached a production of over 13,000 tons per week.

The old workings on the Beresford Seam (4 ft. 6 in. at 1493 ft.) are limited, owing to the fact that in this locality the seam is near the top of the Carboniferous strata and, as worked to the north-east, west or south-west, is approaching the overlying Mesozoic rocks, the workings being barely 40 ft. away from them on the south-west margin of the area. To the north-west the seam splits and for some distance only the upper part has been worked. The line of change from a solid to a split seam trends roughly east and west. In the south-east, where the seam is getting deeper, there has been a little trouble with water, and dirt partings frequently render working unprofitable.

To the south of the shaft the general dip is to the north-east, but appears to be in the reverse direction in the area east of the shaft, though the workings do not continue far enough to prove this definitely. The average thickness of the seam is between 3 and 4 ft. It usually consists of 1 ft. 6 in. or so of good coal at the top, underlain by a fairly persistent parting of variable thickness. The lower part of the seam is sometimes clean, but in places it is divided by one or more partings at irregular intervals.

The Snowdown Hard (3 ft. with partings at 2235 ft.) has a parting of hard sandstone which thickens towards the south-east and renders the seam unworkable. The only development on this seam consists of headings driven within the shaft pillar.

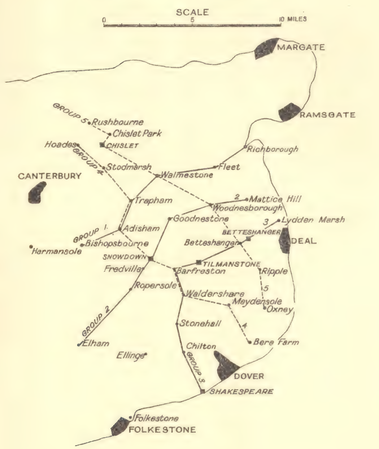
The colliery is at present working on the Millyard Seam (4 ft. 6 in. at 2950 ft.) which averages about 4 ft. in thickness. To the south-west of the shafts the dip of this seam is 1 in 10 to the north-east, and north-west of the shafts it is 1 in 40 or 50 to the south by east, the dips thus being towards the shafts. Faults in this seam are usually found to be at right angles to the dip. The roof is even and rather thinly-bedded sandstone in places, and a bind in others. The floor is a clunch, not a true fireclay.

Tilmanstone (Kent) Colliery Ltd.

The shafts are situated on the west side of the road from Eythorne to Eastry, about a mile north of the former, and six miles north-west by north of Dover.

The No. 1 Shaft was sunk by East Kent Colliery Ltd., and in 1908 was 900 ft. deep. Coal was first got in 1913, but in 1914 water broke into the workings, which necessitated the construction of dams and an alteration in the system of exploitation. In 1926 the company was taken over by one of the debenture holders and worked under its present title. In 1920 sinking was commenced to deepen No. 3 Shaft, but after continuing from 1603 ft. to 1916 ft. work

THE KENT COALFIELD



KEY MAP SHOWING THE GROUPS OF CORRELATED SECTIONS.

The boreholes and shaft sections are shown in groups, plotted relative to Ordnance Datum.
The figures on the left of each section are depths from surface in hundreds of feet, and the figures on the right are thicknesses of the various coal seams.

INDEX

Shales, binds, etc

Sandstone

Fireclays

Thin Coals

Carboniferous Limestone. Zone given where known.

Rocks older than Carboniferous

Marine Bands identified by Bolton except those in Tilmanstone Shaft.

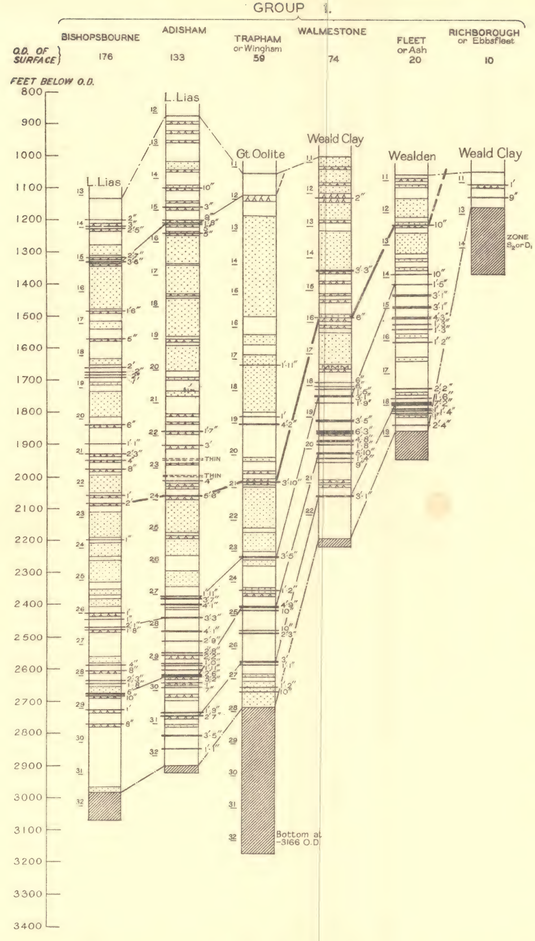
Planes of unconformity marking the top and bottom of the Coal Measures.

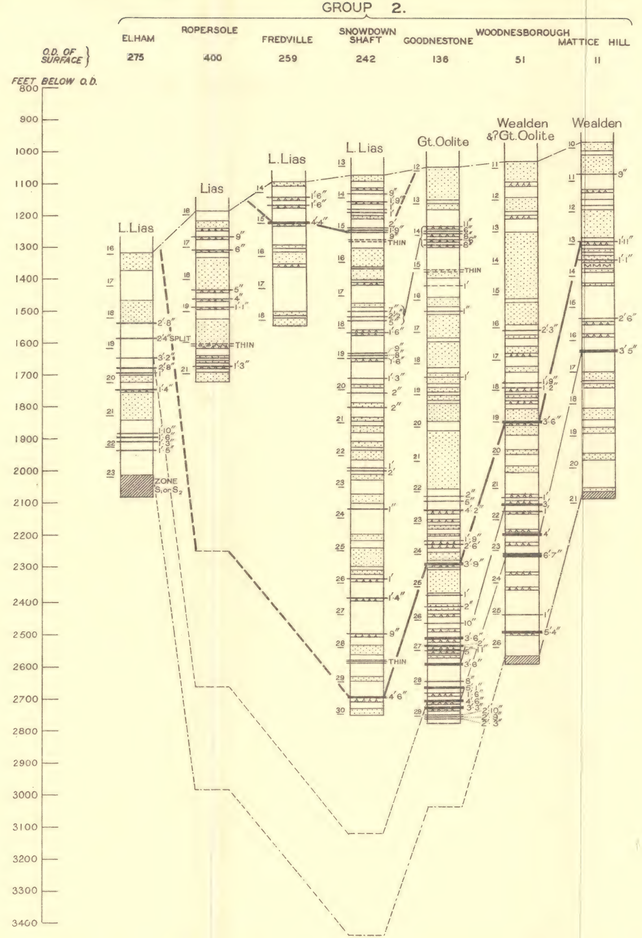
Ditto where conjectural.

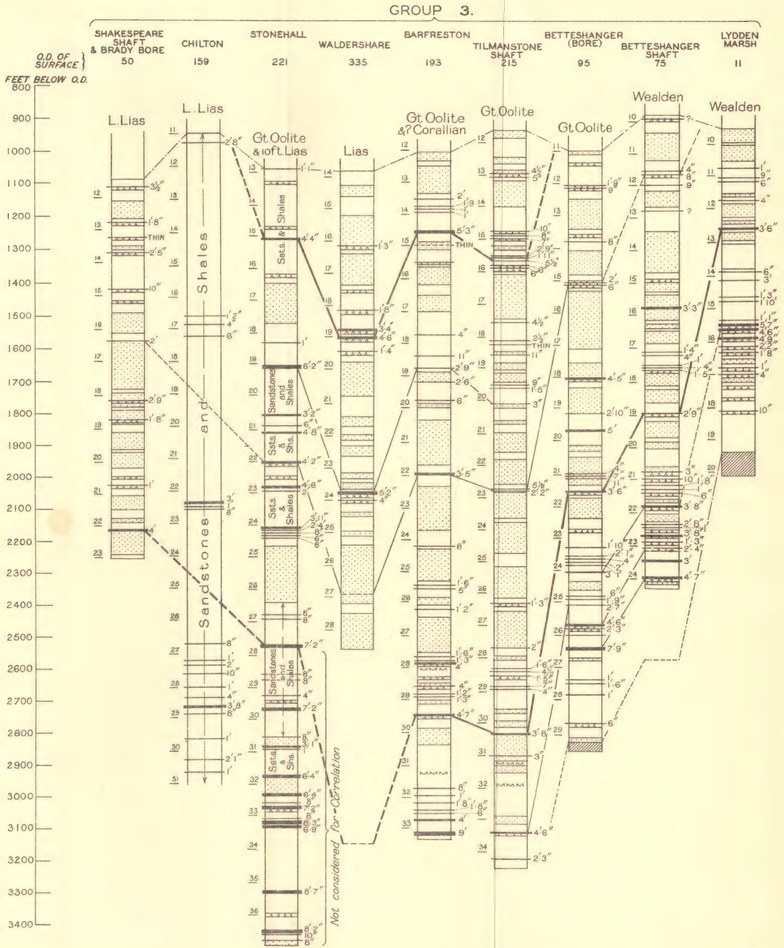
Probable } Correlations of coal seams.

Possible }

The Beresford seam of Tilmanstone and Snowdown Collieries, and the F Seam of Betteshanger Colliery or Millyard Seam of Snowdown Colliery are emphasised by thicker lines. The former is the higher seam.







was stopped. In 1929 it was resumed; the Millyard Seam was struck in May 1930, and a borehole in the bottom of this shaft proved the Coal Measures to a total depth of 3458 ft. The Millyard Seam as proved in the bottom of the shaft at 3035 ft. was 3 ft. 8 in. with dirt partings. The borehole proved a 4 ft. 6 in. seam at 3353 ft. and a 2 ft. 3 in. seam at 3429 ft.

The workings for coal are confined to the Beresford Seam (4 ft. 3 in. with partings at 1549 ft.). This has a very uniform thickness of about 4 ft. There is frequently a 6-in. dirt band at the base with another 1 ft. of coal below. The latter is only reclaimed on drives and headings where the floor is taken out to give the required height. The roof is constant over the whole of the area worked; it consists of shaly bind which forms a good roof, but after weathering for several years in the headings often cracks at right angles to the bedding and falls as blocks a foot or so thick. The seam is massive but thinly bedded, with very few dirt partings. The coal exhibits a starch-like fracture which varies in size in different layers of the coal seam. It is easily worked, but gives as much as 60 per cent. of fines. The seam is very slightly inclined and gently folded, and in some places the roof shows contortions due to compression, though all the faults are normal. The pillar and stall system is employed.

The volatile content of the coal is between 23 and 25 per cent. The output is about 7,500 tons per week.

Betteshanger Colliery (Messrs. Pearson and Dorman Long Ltd.).

The shafts are situated about half a mile north-east of Northbourne, and 2¼ miles west of Deal.

Sinking commenced on the downcast shaft in May 1924 and a depth of 2250 ft. had been reached in 1927, the shaft having been sunk to the ' J ' Seam (3 ft. 8 in.). The upcast shaft was commenced in January 1925, and in July 1927 had been sunk to a depth of 2426 ft. The workings are on the ' F ', ' H ', and ' I ' seams (respectively 2 ft. 9 in. at 1896 ft.; 3 ft. 8 in. at 2154 ft.; and 2 ft. 8 in. at 2228 ft.), the first being presumably the equivalent of the Millyard Seam of Snowdown Colliery. Very little development work has been done on ' F ' and ' I ' seams, the main workings being at present confined to ' H ' Seam. It is intended to develop ' F ' later, by driving cross-measures drifts from the level of ' H.'

On ' F ' Seam headings have only been driven within the shaft pillar.

The ' H ' Seam varies in thickness, the average being between 3 ft. 10 in. and 4 ft. To the east of the shafts the coal increases to a thickness of 9 ft. along a belt coursing north-west by north, but it is followed eastward by a parallel zone of thin coal. The coal is good, with a fairly hard band about 12 or 18 in. thick, near the middle, consisting largely of durain. The roof is variable, being in places bind and in others sandstone, due to lenticular bedding. The sandstone forms a good roof, but the bind may be troublesome.

Some trouble has been experienced in the area west of the shafts, where a bed of 'blacks,' or black shale with thin streaks of bright coal, overlies the seam for some distance. If it is not caught, about a foot thickness of this material breaks away. The roof above is usually good, but the falling of the blacks increases the dirt in the coal, and necessitates washing. The floor of the seam is good, but rolls occur in the western end of the workings. These trend north-west and usually rise a foot or so into the coal.

A little coal has been removed from the 'I' Seam in the area immediately north-west of the shafts. This seam, where worked, is 3 to 4 ft. thick, and yields a fairly good coal, but the fireclay floor rises badly in the headings and there are rolls here and there in the floor.

The whole of the west side of the pit is characterized by gentle folding. A small fault with a north-west by north trend and a throw of 14 ft. to the south-west occurs just south of the shafts on the 'F' Seam. The fault met with in the heading that is being driven south-west from about the middle of the main west drift, has already been described (pp. 35, 36).

The percentage of fines produced from the 'H' Seam at this colliery is low, the hard band in the middle of the seam rendering it possible to raise a considerable proportion of large lumps. The coal has a high calorific value, being very suitable for steam-raising purposes. The fines are washed, sized and graded. An output of over 17,000 tons per week has been reached.

(b) Abandoned Shafts [1]

The Wingham and Stour Valley Colliery.

Situated three-quarters of a mile south-east by east of Wingham Church, on the north side of the road to Staple.

Sinking was commenced in 1910, but the shaft does not appear to have been sunk more than 50 ft. before operations ceased.

Woodnesborough Colliery.

Situated a mile south-west of Woodnesborough Church, south of the road at Denne Court.

Some surface plant was erected in 1910 but no sinking done.

Guilford (Waldershare) Colliery.

Situated half a mile east of Coldred Street, and 1½ miles south by west of Eythorne Station.

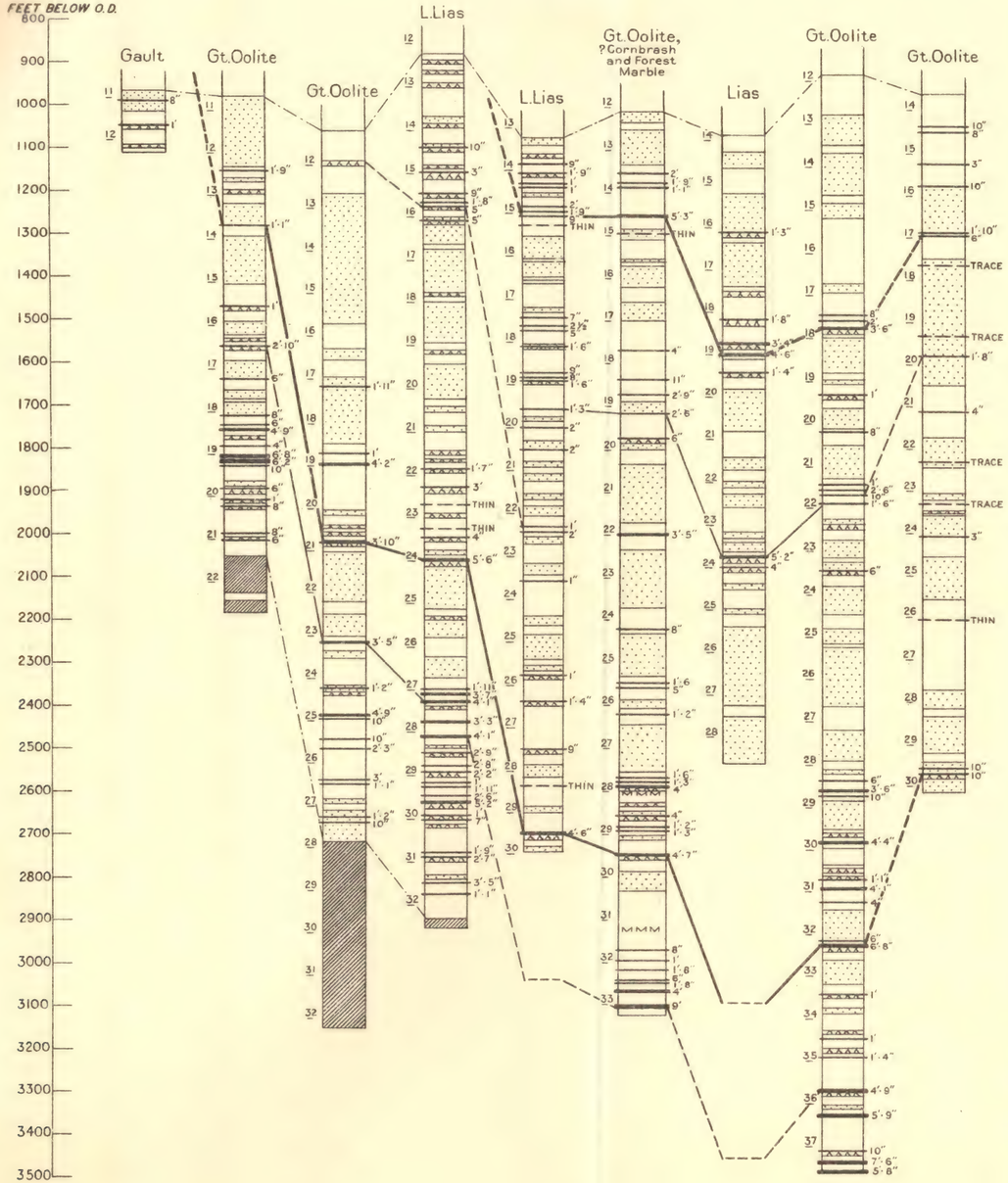
Shafts were commenced in 1911, and the shafts and pilot borehole reached a depth of 1346 ft., but Coal Measures were not penetrated.

The property is now under the control of the Tilmanstone (Kent) Colliery Ltd.

[1] Much of the information given here is obtained from A. E. Ritchie, *op. cit.*

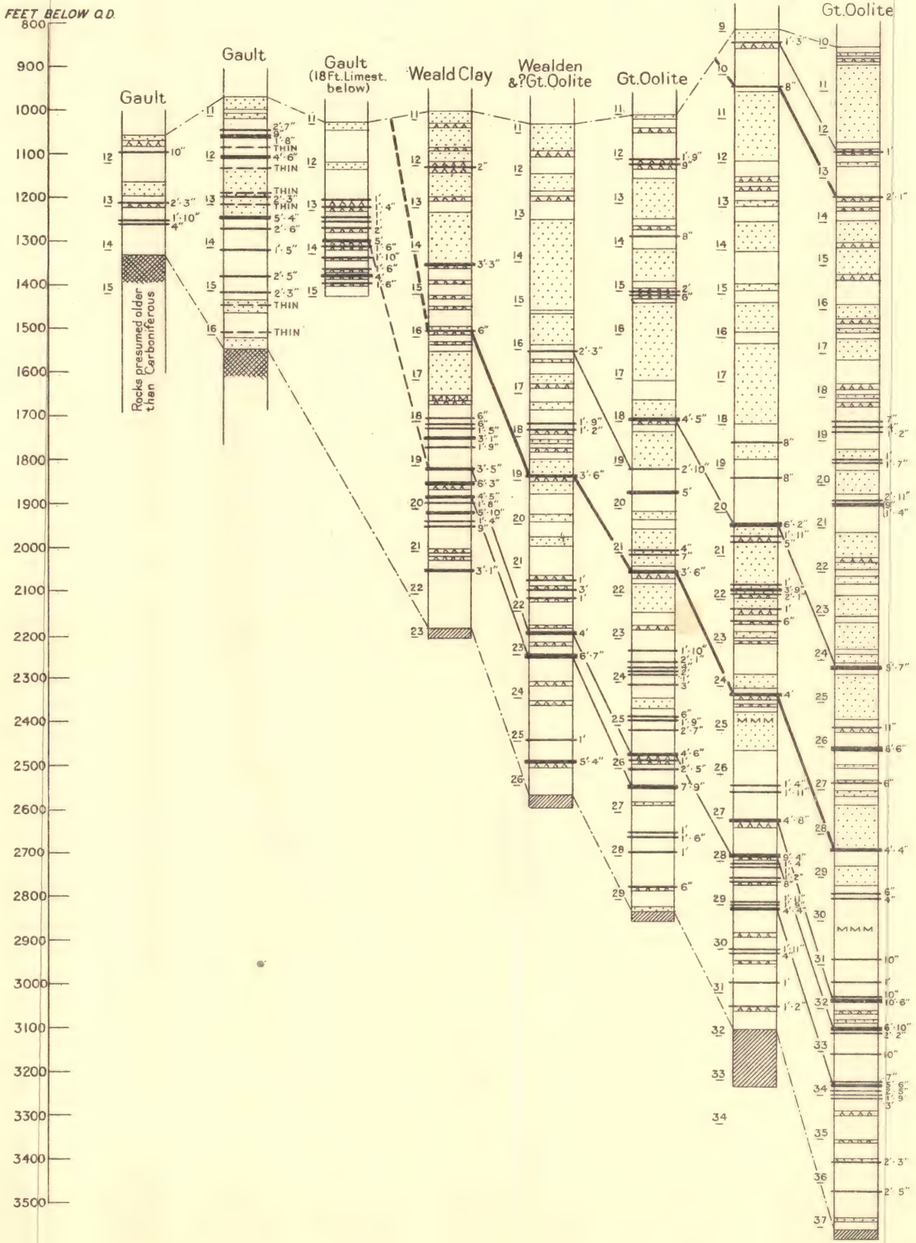
GROUP 4.

O.D. OF SURFACE	HOADES ?120	STODMARSH 87	TRAPHAM 59	ADISHAM 133	SNOWDOWN SHAFT 242	BARFRESTON 193	WALDERSHARE 335	MAYDENSOLE 253	BERE FARM 396



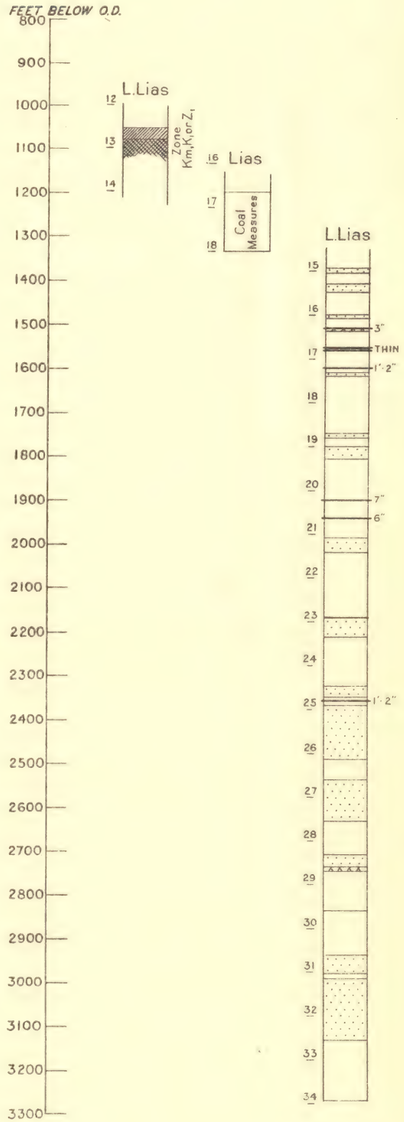
GROUP 5.

O.D. OF SURFACE	RUSHBOURNE 75	CHISLET PARK 50	CHISLET SHAFT 68	WOODNESBOROUGH WALMESTONE 74	WOODNESBOROUGH 51	WOODNESBOROUGH BETTESHANGER (BORE) 95	RIPPLE 66	OXNEY 136



CARBONIFEROUS BORINGS NOT INCLUDED IN THE GROUPS.

O.D. OF SURFACE	HARMANSOLE 200	ELLINGE 460	FOLKESTONE 113



Stonehall Colliery.

Situated on the north slope of the Dour valley, a quarter of a mile east of Lydden Church.

Shaft sinking was commenced in 1913, but operations ceased during the Great War and were not resumed. Coal Measures were not reached.

Shakespeare Colliery.

Situated at the foot of Shakespeare Cliff, about 1½ miles from the Admiralty Pier, Dover Harbour.

Shaft sinking commenced in 1896, but the second shaft had not reached Coal Measures in 1912. A very limited quantity of coal was raised in 1912, but owing to bad water conditions the Coal Measures were sealed off by dams in the shaft in 1915, and drivages were made in the iron-ore bed of the Corallian. Shortly afterwards work was suspended and the water allowed to rise in the shafts.

II.—CONTRIBUTIONS TO THE GEOLOGY OF THE KENT COALFIELD

(II). THE FOSSIL FLORA OF THE KENT COALFIELD

BY

R. CROOKALL, D.Sc., PH.D.

Plates V-VII.

INTRODUCTION

Our knowledge of the palaeobotany of the Kent Coalfield is almost entirely due to the late Dr. E. A. N. Arber,[1] who showed that the upper part of Dr. H. Bolton's ' Upper Series '[2] belongs mainly to the Transition Coal Measures (= Staffordian Stage),[3] and that the lower remaining portion of the Kent Coal Measures must be classed with the true Middle Coal Measures (= Yorkian Stage).[4]

From fossil plants collected in subsequent borings, Dr. R. Kidston[5] proved the presence of the Keele Group (the lower division of the true Upper Coal Measures or Radstockian Stage)[6] in the highest portion of the Kent Coal Measures. He further referred certain beds of Arber's Staffordian Stage to the Etruria Marl and Newcastle-under-Lyme Groups, but it is necessary to point out that the correlation of the subdivisions of the Staffordian Stage by means of plant-remains requires revision.[7]

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[1] Arber, A. E. N., ' On the Fossil Plants of the Waldershare and Fredville Series of the Kent Coalfield,' *Quart. Journ. Geol. Soc.*, vol. lxv, 1909, pp. 21-39, also ' A Note on some Fossil Plants from the Kent Coalfield,' *Geol. Mag.*, 1912, p. 97, and ' On the Fossil Flora of the Kent Coalfield,' *Quart. Journ. Geol. Soc.*, vol. lxx, 1914, p. 54.

[2] Bolton, H., ' The Fauna and Stratigraphy of the Kent Coalfield,' *Trans. Inst. Mining Eng.*, vol. xlix, 1915, pp. 643-702.

[3] See, however, p. 65.

[4] Reference should also be made to R. Zeiller's ' Sur les empreintes du sondage de Douvres,' *C. R. Acad. Sci. Paris*, vol. 140, 1892, and to the observations made by Professor W. J. Jongmans in 1909—' The Flora of the Dutch Carboniferous compared with that of the Adjacent Coalfields,' in van Waterschoot van der Gracht, *Mem. Govt. Inst. Geol. Exploration of the Netherlands* (Rijksopsporing van Delfstoffen), No. 2, 1909, p. 189.

[5] Kidston, R., ' List of the Fossil Plants from the Coal Measures of the Borings at Bere Farm, Elham, Folkestone and Lydden Valley, Kent,' ' Summary of Progress ' for 1918 (*Mem. Geol. Surv.*), 1919, Appendix II, p. 46.

[6] The Keele Group = the Farrington Group. (See R. Crookall, ' Flora and Stratigraphy of the Bristol and Somerset Coalfield,' ' Summary of Progress ' for 1928, Part ii (*Mem. Geol. Surv.*), 1929, p. 82, and 'A Critical Revision of Kidston's Coal Measure Floras,' *Proc. Roy. Phys. Soc. Edin.*, vol. xxii, Part i, 1931, p. 24.)

[7] Dr. Walcot Gibson (' On the Character of the Upper Coal Measures of North Staffordshire,' *Quart. Journ. Geol. Soc.*, vol. lvii, 1901, p. 251, and ' The Geology of the Country around Stoke-upon-Trent ' (*Mem. Geol. Surv.*), 1902, p. 37) divided the Coal Measures of North Staffordshire lying above the Bassey Mine Ironstone into the Blackband, Etruria Marl, Newcastle-under-Lyme and Keele groups. The floras of these divisions were described by Kidston (' On the Divisions and Correlation of the Upper Portion of the Coal Measures,' *Quart. Journ. Geol. Soc.*, vol. lxi, 1905, p. 308), who, on the basis of the fossil plants, correlated beds of Staffordian age in other parts of the country with these groups. In the discussion following Kidston's paper, however, Dr. Wheelton Hind pointed out that (a) the Bassey Mine was unsuitable as the base of a subdivision, as the flora and fauna above and below it showed no change, and (b) he made his subdivision at the horizon of the Gubbin Ironstone. Dr. Gibson (in the Third Edition of ' The Geology of the Country around Stoke-upon-Trent,' 1925, p. 38) recently suggested that the Blackband Group might be extended down to the Cannel Row Coal. Miss E. Dix has traced the Staffordian flora to a line just below the Chalky Mine Ironstone, about 400 ft. below the Bassey Mine (see ' The Flora of the Upper Portion of the Coal Measures in North Staffordshire,' *Quart. Journ. Geol. Soc.*, vol. lxxxvii, 1931, p. 160) and it is evident that Kidston's correlations of Staffordian beds in other parts of the country with Dr. Gibson's subdivisions in North Staffordshire cannot stand.

In 1930, in collaboration with Dr. John Pringle, the writer[1] published a review of the palaeobotany of the area as then known. During the present work, collections were made at the four pits working, both by Mr. W. Dewar and the writer, and over 900 selected plant specimens are preserved in the collections of the Geological Survey, London. In the lists of species which follow, the frequency with which a given form occurs on any horizon is shown by means of numbers, thus: 1—2 = very rare: 3—4 = fairly rare: 6—7 = fairly common: 8—10 = very common. For purposes of future reference and revision the registered numbers of representative fossils on the chief horizons are given (in brackets). These precede the numbers representing frequency of occurrence.

The proximity of the Kent Coalfield to that of the North of France involved the desirability of attempting a correlation with that area, as well as with the neighbouring British coalfields. Professor P. Bertrand of Lille visited London in 1932, examined the specimens, made correlations with the French Coal Measures (see p. 64), and expressed agreement with the British correlations here given. The writer wishes to thank Professor Bertrand for this most valuable assistance.

Floras and Analyses

Locality: **Chislet Colliery,** $1\frac{3}{4}$ miles S.S.W. of Chislet, Kent (one-inch Sheet 273; six-inch Sheet Kent 36 S.W.).

Horizon: No. 5 Seam—Yorkian Stage.

Remarks: This, the only seam at present worked at Chislet, is about four feet thick. The roof changes from hard grey sandstone on the west side to blue bind on the east.

FILICALES AND PTERIDOSPERMEAE	Frequency
Alethopteris decurrens (*Artis*) (Nos. KP. 474-481)	4
,, lonchitica (*Schlotheim*) (No. KP. 262)	2
,, valida *Boulay* (Nos. KP. 45, 47)	1
Aphlebia gigantea *Zeiller* (No. 50618)	2
Dactylotheca plumosa (*Artis*) (No. KP. 39)	3
Neuropteris callosa *Jongmans & Gothan*[2] (No. KP. 251) ...	5
,, heterophylla *Brongniart* (Nos. KP. 356, 367, 807-822)	10
,, obliqua *Brongniart* (Nos. KP. 357, 794-806) ...	5
,, pseudogigantea *Potonié* (Nos. KP. 368, 430) ...	6
,, tenuifolia (*Schlotheim*) (Nos. KP. 783-793) ...	10
Mariopteris *aff.* carnosa *Corsin*[2] (No. KP. 494)	1
,, ? hirta *Stur* (No. KP. 245)	1
,, ? jacquoti *Zeiller* (No. KP. 493)	1
,, ? nervosa (*Brongniart*) (No. KP. 242)	2

[1] Pringle, J., and R. Crookall, 'Palaeobotany of the Kent Coalfield,' *Proc. Geol. Assoc.*, vol. xli, 1930, pp. 180-189.
[2] *Fide* Professor Bertrand.

	Frequency
Sphenopteris dilatata *Lindley & Hutton* (Nos. KP. 352, 491, 492)	3
,, sp. (No. KP. 431)	3
? Microsporangia of pteridosperm (Nos. KP. 434, 435)	1
? Fern sporangia (Nos. KP. 443, 444)	1
LYCOPODIALES	
Bothrodendron minutifolium (*Boulay*) (Nos. KP. 361, 362, 363, 448)	7
Lepidodendron aculeatum *Sternberg* (No. KP. 256)	2
,, sp.	1
Lepidostrobus morissianus *Lesquereux* (No. KP. 433)	1
Lepidophyllum sp.	1
Lepidophloios acerosus *Lindley & Hutton* (Nos. KP. 351, 369, 449)	3
Sigillaria tessellata *Brongniart* (Nos. KP. 43, 446, 447)	3
,, sp.	2
Stigmaria minuta *Goeppert* pro var. (No. KP. 490)	5
EQUISETALES	
Annularia galioides *Lindley & Hutton*[1] (Nos. KP. 358, 364, 1436-9)	3
,, microphylla *Sauveur*[1] (No. 50576)	5
,, radiata *Brongniart* (Nos. KP. 359, 421-423)	5
,, sphenophylloides (*Zenker*) (Nos. KP. 424-9)... ...	4
Asterophyllites charaeformis (*Sternberg*) (No. KP. 432)... ...	10
,, grandis (*Sternberg*) (Nos. KP. 170, 173)... ...	5
Calamites carinatus *Sternberg* (No. 50574)	8
,, goepperti *Ettingshausen* (No. KP. 168)	4
,, sachsei *Stur* (Nos. KP. 247, 442)	2
,, suckowi *Brongniart* (No. KP. 182)	6
,, undulatus *Sternberg* (Nos. KP. 445, 50577)	10
Calamophloios sp. (No. KP. 441)	4
SPHENOPHYLLALES	
Sphenophyllum cuneifolium (*Sternberg*) (Nos. KP. 366, 370, 453-9)	10
,, myriophyllum *Crépin* (Nos. KP. 360, 363) ...	6
,, saxifragaefolium (*Sternberg*) (Nos. KP. 482-486)	6
CORDAITALES	
Cordaites sp.	1
SEMINA INCERTAE SEDIS	
Neuropterocarpus sp. (No. KP. 253)	2
Holcosperma sp. (Nos. KP. 451, 452)	2

Analysis : The No. 5 Seam at Chislet is accompanied by a very distinctive flora where the roof consists of shale, the chief elements being *Alethopteris lonchitica*,[2] *A. valida*,[2] *Neuropteris pseudogigantea*,[2] *N. callosa*,[2] *N. heterophylla*,[2] *N. tenuifolia*,[2] *Sphenopteris dilatata*,[2] *Bothrodendron minutifolium*,[2] *Lepidophloios acerosus*, *Stigmaria minuta*, *Annularia galioides*, *A. microphylla*, *A. radiata*, *Asterophyllites charaeformis*, *A. grandis*, *Calamites goepperti*, *C. undulatus*, *Sphenophyllum cuneifolium*[2] and *S. myriophyllum*.[2]

[1] These two forms are listed separately although there is evidence to show that they belong to a single species.

[2] These are the forms most diagnostic of a Yorkian horizon.

All these species are more or less frequent on the horizon and, though several are found to accompany certain other seams in the Kent Coalfield, some of these (e.g. *Bothrodendron minutifolium* and *Stigmaria minuta*) do not occur elsewhere in the area in anything approaching this frequency. *B. minutifolium* is the only common Lycopod, while Eupecopterids are absent. On the other hand, *Calamites* is a very common genus, being represented by several stem- and leaf-species. Broken nodes of these stems ('phragmae') and casts of the outer surface of the stems (*Calamophloios*) are correspondingly common.

The above is a Yorkian flora.

While collecting from the No. 5 Seam at Chislet, the writer obtained a number of well-preserved insect wings, some of which appear to be new species.

Locality: **Chislet Colliery,** cross-measures drift at end of Main West Drift.

Horizon: Roof of a coal seam at 1296 ft. below O.D.—Yorkian Stage.

Remarks: The roof of this seam consists of a hard unfossiliferous sandstone, current-bedded. Plant-remains are badly preserved and broken.

	Frequency
Neuropteris heterophylla *Brongniart*	1
Bothrodendron minutifolium (*Boulay*)	1
Sigillaria sp.	1
Calamites suckowi *Brongniart*	1

Horizon: About 30 ft. below No. 5 Seam at 1325 ft. below O.D.—Yorkian Stage.

Neuropteris heterophylla *Brongniart*	1
Mariopteris sp.	1
Rhodea sp.	1
Asterophyllites grandis (*Sternberg*)	1
Calamophloios sp.	1
Sphenophyllum saxifragaefolium (*Sternberg*)	2
Lepidophyllum sp.	1

Horizon: Plant-bed at 1328 ft. below O.D.—Yorkian Stage.

Neuropteris heterophylla *Brongniart*	4
,, gigantea *Sternberg*	1
Calamites undulatus *Sternberg*	1
Lepidostrobus sp.	1
Cordaites principalis (*Germar*)	1

Horizon: Plant-bed at 1330 ft. below O.D.—Yorkian Stage.

Neuropteris heterophylla *Brongniart*	6
Cordaites borassifolius (*Sternberg*)	3
,, sp.	1

Horizon: Plant-bed at 1332 ft. below O.D.—Yorkian Stage.

Neuropteris gigantea *Sternberg*	1

Horizon : Plant-bed at 1333 ft. below O.D.—Yorkian Stage.

	Frequency
Neuropteris heterophylla *Brongniart*	5
,, gigantea *Sternberg*	1
Stigmaria ficoides (*Sternberg*)	1
Lepidodendron *cf.* jaraczewski *Zeiller*	1
Calamites sp.	1
Carpolithus sp.	1

Horizon : Plant-bed at 1334 ft. below O.D.—Yorkian Stage.

Neuropteris obliqua *Brongniart*	1
,, scheuchzeri *Hofmann*	1
Sigillaria boblayi *Brongniart*	1
Cordaites borassifolius (*Sternberg*)	1
Pinnularia capillacea (*Lindley & Hutton*)	2
Samaropsis sp.	1

Horizon : Plant-bed at 1336 ft. below O.D.—Yorkian Stage.

Alethopteris ? lonchitica (*Schlotheim*)	1
Neuropteris gigantea *Sternberg*	1
,, heterophylla *Brongniart*	1
Sigillaria tessellata *Brongniart*	1

Horizon : Plant-bed at 1338 ft. below O.D.—Yorkian Stage.

Alethopteris ? lonchitica (*Schlotheim*)	1
Neuropteris heterophylla *Brongniart*	2
Cordaites sp.	1

Horizon : Plant-bed at 1338½ ft. below O.D.—Yorkian Stage.

Neuropteris heterophylla *Brongniart*	1
Calamites schützeiformis *Kidston & Jongmans*	1
Cordaites sp.	1

Horizon : Plant-bed at 1340 ft. below O.D.—Yorkian Stage.

Eremopteris artemisaefolia (*Sternberg*)	1
Neuropteris heterophylla *Brongniart*	1
,, *cf.* obliqua *Brongniart*	1
,, sp.	1
Cordaites borassifolius (*Sternberg*)	1

Horizon : Plant-bed at 1342 ft. below O.D.—Yorkian Stage.

	Frequency
Neuropteris sp.	2
Asterophyllites grandis (*Sternberg*)	2
Annularia *cf.* galioides (*Lindley & Hutton*)	1
Dorycordaites palmaeformis (*Goeppert*)	1

Horizon : Roof of a coal seam. Plant-bed at 1342½ ft. below O.D.—Yorkian Stage.

Remarks : This coal varies in thickness from 1 ft. 6 in. to 3 ft. 1 in. The roof is a hard grey bind and is overlain by a two-foot band of moderately hard bind.

	Frequency
Neuropteris gigantea *Sternberg*	1
Calamites suckowi *Brongniart*	3
Sphenophyllum myriophyllum *Crépin*	3
Sigillaria sp.	1

Horizon : Plant-bed at 1413 ft. below O.D.

	Frequency
Neuropteris heterophylla *Brongniart*	2
,, scheuchzeri *Hofmann*	1
Sigillaria elongata *Brongniart*	1
Calamites sp.	3
Cordaites borassifolius (*Sternberg*)	10

Remarks : This horizon is remarkable for the presence of a large number of specimens of *Cordaites borassifolius*. The record of *Neuropteris scheuchzeri* is also noteworthy. All the fossils are in shales.

Horizon : Roof of a coal seam. Plant-bed at 1464 ft. below O.D.—Yorkian Stage.

Remarks : This coal is about 4 ft. 6 in. thick. The roof consists of a mixture of fireclay and shales.

	Frequency
Sigillaria sp.	1

Analysis : The whole of the seams passed through up to this point in the Main West Drift are in the Yorkian Stage. This is shown by the entire absence from the floras of the Cyatheites-Pecopterids and by the frequent presence of such species as *Neuropteris heterophylla, N. pseudogigantea, Alethopteris lonchitica* and *Sphenophyllum myriophyllum.*

Horizon : Plant-bed at 1464½ ft. below O.D.

The seam of coal struck at this depth has a general thickness of 4 ft. 6 in. The roof consists of sandstone and yielded only the following fossils—*Mariopteris sp., Neuropteris sp., Lepidostrobus morissianus* Lesquereux and *Calamites suckowi* Brongniart. On this evidence it is open to doubt whether the new seam is identical with the No. 5 Seam, though the lithological evidence suggests that conclusion.[1]

Locality : **Snowdown Colliery,** 2⅛ miles N.N.W. of Shepherdswell, Kent (one-inch Sheet 289, six-inch Sheet Kent 57 N.E.).

Horizon : Millyard[2] Seam—Staffordian Stage.

Remarks : The Millyard Seam is the only one at present worked at this pit: it is at a depth of 3000 ft. from surface, some 500 yds. below the Beresford Seam. The roof consists of a carbonaceous shale with many plant-remains, though these are usually fragmentary, macerated and unrecognisable. Above the carbonaceous

[1] Since the above was written the writer obtained several species of fossil plants from the roof of the seam in the Main West Drift. They include *Calamites undulatus, Neuropteris heterophylla, N. microphylla* and *Alethopteris lonchitica*, species which are also known from the roof of the No. 5 Seam. An insect wing occurred in association with these plants.

[2] Often spelt 'Milyard.'

shale is a soft grey shale which is almost barren of plants, though containing shells. Drifted leaves and bracts (*Lepidophyllum* and *Lepidostrobus*) occur, along with shells, in this shale.

	Frequency
FILICALES AND PTERIDOSPERMEAE	
Alethopteris sp. (No. KP. 143)	1
Asterotheca miltoni (*Artis*) (No. KP. 164)	1
Linopteris obliqua (*Bunbury*) (Nos. KP. 394, 764-769)	4
Neuropteris heterophylla *Brongniart* (No. KP. 136)	3
,, spp. (No. KP. 148)	4
Sphenopteris? striata *Gothan* (No. KP. 160)	1
,, sp. (Nos. KP. 777, 778)	2
LYCOPODIALES	
Lepidodendron aculeatum *Sternberg* (No. KP. 763)	2
,, acutum (*Presl*) (No. KP. 135)	1
,, dichotomum *Sternberg* (No. KP. 151)	3
,, *cf.* jaraczewski *Zeiller* (Nos. KP. 272, 273)	1
,, obovatum *Sternberg* (Nos. KP. 774-6)	2
,, rimosum *Sternberg* (No. KP. 150)	2
,, sp. (No. KP. 147)	2
Lepidostrobus brevifolius (*Lesquereux*) (No. KP. 140)	3
,, goodei *Jongmans*[1] (Nos. KP. 393, 770-3)	3
,, triangularis (*Zeiller*) (No. KP. 280)	1
Sigillaria sp.	3
EQUISETALES	
Calamites carinatus *Sternberg* (No. KP. 145)	3
,, suckowi *Brongniart* (No. KP. 279)	4
,, sp. (No. KP. 147)	6
Calamitic cones	2
Annularia sphenophylloides (*Zenker*) (No. KP. 158)	1
SPHENOPHYLLALES	
Sphenophyllum majus (*Bronn*) (Nos. KP. 276, 277)	1
CORDAITALES	
Artisia approximata *Brongniart*	1
Cordaites sp.	3
SEMINA INCERTAE SEDIS	
Carpolithus sp. (Nos. KP. 779, 780)	6
Holcosperma fimbriatum *Crookall n. sp.* (No. 49370)	1
,, sp.	1
Samaropsis reniformis (*Geinitz*) (Nos. KP. 138, 138a)	1
,, sp. (Nos. KP. 781, 782)	1

Analysis: The Millyard Seam at Snowdown Colliery is characterised by the following species: *Linopteris obliqua, Neuropteris heterophylla, Lepidodendron acutum, L. dichotomum, L. obovatum, L. rimosum, Sphenophyllum majus, Annularia sphenophylloides, Holcosperma fimbriatum* and *Samaropsis reniformis.* Of these, the chief zonal forms are:—*Linopteris obliqua, Neuropteris heterophylla, Annularia sphenophylloides* and *Sphenophyllum majus.*

[1] This is the *L. minus* Goode (*non* Schenk).

The absence of the Cyatheites-Pecopterids precludes a reference of this seam to the Radstockian Stage. The flora is a 'mixed' one, consisting of some few Radstockian and certain Yorkian species. The horizon must, therefore, be referred to the Staffordian Stage. The most diagnostic Staffordian species is *Linopteris obliqua.*

Though Lycopods are by no means common in the flora dealt with above, they are more frequent than in the floras of most of the seams collected from in the present revision of the coalfield. The examples of *Sigillaria* recorded were all in sandstone and were specifically unidentifiable.

Locality: **Tilmanstone Colliery,** No. 1 Shaft, 1⅛ miles S.W. of Tilmanstone, Kent (one-inch Sheet 290; six-inch Sheet Kent 58 N.W.).

Horizon: Beresford Seam—Radstockian Stage.

Remarks: The Beresford is the only seam at present worked at this pit. The roof consists of shale merging in parts into a sandy bind.

FILICALES AND PTERIDOSPERMEAE	Frequency
Alethopteris serli (*Brongniart*) (Nos. KP. 50, 292, 295, 297-299)	9
Aphlebia spinosa *Lesquereux*	1
Asterotheca micro-miltoni (*Artis*) (Nos. KP. 48, 284)	5
Eupecopteris sp. (Nos. KP. 58, 63, 303, 307)	4
Mariopteris nervosa (*Brongniart* non *Zeiller*) (Nos. KP. 131, 132)	4
,, sp. (No. KP. 349)	1
Neuropteris flexuosa (*Sternberg*) (Nos. KP. 333, 334)	4
,, rarinervis *Bunbury* (Nos. KP. 49, 314, 339-342, 343)	3
,, scheuchzeri *Hofmann* (Nos. KP. 48, 54)	10
Odontopteris lindleyana *Sternberg* (No. KP. 353)	3
Sphenopteris neuropteroides (*Boulay*) (No. KP. 50)	4
Spiropteris...	2
LYCOPODIALES	
Lepidodendron sp. (No. KP. 59)	1
Sigillaria brardi *Brongniart*	1
Sigillaria sp.	1
Lepidostrobus lanceolatus (*Lindley & Hutton*) (Nos. KP. 52, 282)	1
Sigillariophyllum bicarinatum (*Lindley & Hutton*) (No. KP. 49)	1
?Lycopodites sp.	2
EQUISETALES	
Calamites sp.	2
Annularia ? galioides (*Lindley & Hutton*) (No. KP. 287) ...	1
,, sphenophylloides (*Zenker*) (Nos. KP. 133, 288) ...	6
,, stellata (*Schlotheim*) (Nos. KP. 286, 290)	4
SPHENOPHYLLALES	
Sphenophyllum emarginatum *Brongniart* (Nos. KP. 55, 62, 291, 296)	7
,, majus (*Bronn*) (No. KP. 55)	3
CORDAITALES	
Cordaites sp.	1
Samaropsis sp.	1

EX BIBL. UNIV. EDINBURGEN. *

	Frequency
SEMINA INCERTAE SEDIS	
Cornucarpus arberi (*Kidston MS.*) *Crookall* (No. KP. 65) ...	1
Trigonocarpus noeggerathi (*Sternberg*)	3
INCERTAE SEDIS	
Pinnularia capillacea (*Lindley & Hutton*) (No. KP. 57)	3

Analysis : The chief zonal species are *Sigillaria brardi*, *Odontopteris lindleyana*, *Alethopteris serli*, *Eupecopteris spp.*, *Neuropteris flexuosa*, *N. rarinervis*, *N. scheuchzeri*, *Sphenopteris neuropteroides*, *Annularia sphenophylloides* and *Sphenophyllum emarginatum*. Yorkian plants are absent. The occurrence of the Eupecopterids and the associated forms at once suggests the Radstockian Stage. There is no admixture of Yorkian forms, while *Linopteris obliqua* and other Staffordian plants are unrecorded.

In referring the horizon to one of the two subdivisions of the Radstockian Stage (the Farrington Group and the Radstock Group), it should be noted that recognisable Pecopterids of a Stephanian type, such as begin to appear in the higher (Radstock) Group, are absent—species such as *Ptychocarpus unitus* (Brongniart), *Dicksonites pluckeneli* (Schlotheim), *Acitheca polymorpha* (Brongniart), *Asterotheca candolleana* (Brongniart) and *A. lamuriana* (Heer). It may also be pointed out that *Sphenophyllum majus* is unknown from the Radstock Series of Somerset. On the other hand, all the zonal species enumerated have been recorded from the Farrington Series of Somerset. The Beresford Seam at Tilmanstone is therefore referred to a low position in the Radstockian —in the Farrington Group—and this is the highest plant division recognised in the Kent Coal Measures.

Locality : **Tilmanstone Colliery,** No. 3 Shaft sinking.

Horizons : As given (in feet below surface).

	Frequency
At 2790-2794 ft.	
Neuropteris scheuchzeri *Hofmann* (No. KP. 9)	2
Sphenopteris nummularia *Gutbier* (No. KP. 8)	1
Sphenophyllum emarginatum *Brongniart* (No. KP. 2)	1
At 2819-2834 ft.	
Neuropteris rarinervis *Zeiller* (*? Bunbury*) (No. KP. 18) ...	1
,, sp. (No. KP. 12)	1
Sphenopteris neuropteroides (*Boulay*) (Nos. KP. 16, 17) ...	2
Annularia sphenophylloides (*Zenker*) (No. KP. 15)	1
Sphenophyllum emarginatum *Brongniart* (No. KP. 20) ...	1
,, majus (*Bronn*) (No. KP. 15)	2
Carpolithus sp. (No. KP. 10)	1

Analysis : The flora given above is remarkable for the scarcity of examples of the Lycopodiales, a feature which is to be observed on a number of horizons in the Kent Coalfield. The assemblage is a ' mixed ' one so far as Radstockian and Yorkian forms are concerned, and the beds must be referred to the Staffordian Stage. Those

Radstockian species which are recorded (*Neuropteris scheuchzeri*, *Sphenopteris neuropteroides*, *Sphenophyllum emarginatum* and *Annularia sphenophylloides*) are also found in the Staffordian Stage. The absence of a number of forms, and particularly of examples of the Cyatheites-Pecopterids, precludes a reference to the Radstockian, while the few Yorkian forms are very rare. *Sphenopteris neuropteroides* is as yet unrecorded from Yorkian horizons. *Sphenophyllum majus* is recorded (on p. 50) from the Millyard Seam—a Staffordian horizon.

	Frequency
At 2830-2834 ft.	
Cornucarpus arberi (*Kidston MS.*) *Crookall* (Nos. KP. 21, 22) ...	1
Samaropsis sp. (No. KP. 23)	1
At 2834-2835½ ft. (top of Six-feet-one-inch Coal)	
Lepidophyllum sp. (Nos. KP. 24, 25)	1
At 2902 ft.	
Neuropteris heterophylla *Brongniart* (No. KP. 66)	1
At 2916-2924 ft.	
Neuropteris heterophylla *Brongniart* (No. KP. 66)	1
,, tenuifolia (*Schlotheim*) (No. KP. 67)	1
Sphenophyllum cuneifolium (*Sternberg*) (No. KP. 68)	1
At 2960 ft.	
Neuropteris heterophylla *Brongniart* (Nos. KP. 69-72)	1
Calamites suckowi *Brongniart* (No. KP. 73)	1
At 2966 ft.	
Neuropteris heterophylla *Brongniart* (No. KP. 74)	1
,, sp. (No. KP. 77)	1
Sphenophyllum? cuneifolium (*Sternberg*) (No. KP. 74) ...	2
Between 2966 and 2970 ft.	
Neuropteris heterophylla *Brongniart* (No. KP. 126)	1
,, rarinervis *Zeiller* (No. KP. 75)	1
Annularia sphenophylloides (*Zenker*) (No. KP. 125)	1
Asterophyllites equisetiformis (*Schlotheim*) (No. KP. 125) ...	2
Cornucarpus arberi (*Kidson MS.*) *Crookall* (No. KP. 127) ...	1
At 2975 ft.	
Neuropteris tenuifolia (*Schlotheim*) (No. KP. 128)	1
Carpolithus sp. (No. KP. 129)	1

Analysis: Although the beds below 2830 ft. in the No. 3 Shaft sinking at Tilmanstone have not yielded a great variety of species, they may be referred to the Staffordian Stage, all the recorded plants being known elsewhere from that division. A coal which is regarded as the equivalent of the Millyard Seam at the Snowdown Colliery was struck in this shaft at a depth of 3035 ft., but no plants were obtained from the roof. This coal, which, at Snowdown, is from 5 to 6 ft. in thickness, here measures only about three feet, and, moreover, contains a fair proportion of 'dirt.'

From a depth of 3058 ft. a borehole was put down. The following species were obtained:—

Calamites suckowi *Brongniart* (at 3231 ft.) (No. Ba. 3446)
,, sp. (at 3254 ft.) (No. Ba. 3448)
Neuropteris scheuchzeri *Hofmann* (at 3254 ft.) (No. Ba. 3449)
Cordaites borassifolius (*Sternberg*) (at 3266 ft.) (No. Ba. 3452)

Neuropteris tenuifolia (*Schlotheim*) (at 3266 ft.) (No. Ba. 3452)
,, pseudogigantea *Potonié* (at 3266 ft.) (No. Ba. 3453)
,, tenuifolia (*Schlotheim*) (at 3270 ft.) (No. Ba. 3455)
Asterophyllites equisetiformis (*Schlotheim*) (at 3287 ft.) (No. Ba. 3456)
Neuropteris tenuifolia (*Schlotheim*) (at 3288 ft.) (No. Ba. 3457)
,, sp. (at 3333 ft.) (No. Ba. 3458)
Sphenopteris neuropteroides ? (*Boulay*)—specimens (Nos. KP. 2469, 2470) not typical, having dentate margins to the pinnules—(at 3384 ft.)
Corynepteris coralloides (*Gutbier*) (at 3390 ft.) (No. Ba. 3471)

Analysis : In the absence of more diagnostic forms, the beds up to 3384 ft. could belong either to the Staffordian or to the Yorkian Stage and probably should be referred to the former. At 3390 ft. *Corynepteris coralloides* has been found. It occurs in Britain as follows[1]: (a) a single record from the No. 3 Rhondda Seam of Glamorganshire, at the base of the Staffordian Stage, and (b) a few records from the Yorkian of the Lancashire, Nottinghamshire, Warwickshire and South Wales coalfields. Although the species is not a primary zonal form, either in Britain or in the coalfields of the North of France, its occurrence suggests that the Yorkian is entered at about this level.

The No. 3 Shaft at Tilmanstone has not provided a definitely Yorkian assemblage, while species characteristic of the Lanarkian Stage in other British coalfields are unrecorded—forms such as *Sphenopteris hoeninghausi* Brongniart, *S. baeumleri* Andrae, *Neuropteris schlehani* Stur, *Sigillaria elegans* Brongniart and *Sphenophyllum amplum* Kidston *pro sp.*[2]

Locality : **Betteshanger Colliery,** ¾ mile N.N.E. of the Church, Northbourne, Kent (one-inch Sheet 290; six-inch Sheet 48 S.W.).

Horizon : Roof of the 'F' Seam. At depth of 1818 ft. below O.D.

Remarks : The roof of the 'F' Seam (regarded as the equivalent of the Millyard Seam at Snowdown Colliery) varies in character from a dark, rather soft, bind (bluish shale) with an irregular thin nodular ironstone band to a hard micaceous sandy bind. In this roof shells are common but poorly preserved. Plants, on the other hand,

[1] Kidston, R., 'Fossil Plants of the Carboniferous Rocks of Great Britain' (*Mem. Geol. Surv.*, Palaeontology), vol. ii, 1923-5, pp. 300, 301.

[2] See R. Crookall, 'A Critical Revision of Kidston's Coal Measure Floras,' *Proc. Roy. Phys. Soc. Edin.*, vol. xxii, 1931, p. 23; 'The Supposed 'Lanarkian' in Shropshire,' *The Naturalist*, 1932, p. 40; 'The Relative Value of Fossil Plants in the Stratigraphy of the Coal Measures,' *Mem. & Proc. Manchester Lit. & Phil. Soc.*, vol. lxxvi, pp. 112, 113; *in* T. Robertson, 'The Geology of the South Wales Coalfield, Part V, Merthyr Tydfil' (*Mem. Geol. Surv.*), 2nd ed., 1933, p. 239; E. Dix, in *Rep. Proc. Fifth International Botanical Congress, Cambridge*, 1931, p. 490; and R. G. Absalom, 'Coal Measure Floras,' *Geol. Mag.*, vol. lxx, 1933, p. 96. As has been observed by the writer (*op. cit.*, 1931, p. 23) the British Coal Measure floras as now recognised, are generally comparable with those of the Continent. See, for example, H. Potonié, 'Die floristische Gliederung des deutschen Carbon und Perm,' *König. Preuss. geol. Landes.*, N.F., Heft 21, 1896; L. Cremer, 'Ueber die fossilen Farne des Westfälischen Carbons und ihre Bedeutung für Gliederung des letzteren,' *Marburg*, 1893; R. Zeiller, 'Flore Fossile du Bassin Houiller de Valenciennes,' *Etudes des Gîtes Minéraux de la France*, Paris, 1886-8; 'Sur les Subdivisions du Westphalien du Nord de la France,' *Compte-rendu*, 3 Sér., vol. xxii, 1894, p. 487; W. Gothan, Leitfossilien, Karb. und Perm., *Berlin*, 1923, p. 181; W. J. Jongmans, 'The Flora of the Dutch Carboniferous compared with that of the Adjacent Coalfields,' *in* van Waterschoot van der Gracht, *Mem. Govt. Inst. Geol. Exploration of the Netherlands* (Rijksopsporing van Delfstoffen), No. 2, 1909, pp. 162-247; 'Stratigraphische untersuchungen im Karbon von Limburg (Niederlande),' *Congrès de Stratigraphie Carbonifère, Heerlen*, 1927, 1928, pp. 335-396, and the references given to the work of P. Bertrand on p. 66.

are comparatively scarce. ' G ' seam represents a series of bands of coal which is not worked.

	Frequency
Pecopteris *aff.* pennaeformis *forma* major *Brongniart* (No. KP. 83)	1
Mariopteris sp. (No. KP. 84)	1
Linopteris obliqua (*Bunbury*) (No. KP. 82)	1
Sphenophyllum majus (*Bronn*) (No. KP. 80)	1
,, sp. (No. KP. 81)	1
Lepidostrobus lanceolatus (*Lindley & Hutton*)	1
Lepidocystis sp.	1

Analysis : The two satisfactory species recognised in the above flora, namely *Linopteris obliqua* and *Sphenophyllum majus*, have been recognised in the shales forming the roof of the Millyard Seam at the Snowdown Colliery. *Lepidostrobus lanceolatus* possesses no stratigraphical value.

Horizon : Roof of the ' H ' Seam. At a depth of 2075 ft. below O.D.

Remarks : The roof of the ' H ' Seam, the chief coal worked at the Betteshanger Colliery, is somewhat variable, but mainly consists of a dark, sandy, compact bind. The roof is intersected in all directions by oblique 'slips.' On the east side is a mudstone with occasional sandstones ; on the west the chief rock is sandstone with subsidiary patches of mudstone. The sandstone is very coarse and extremely hard, often containing 88 per cent. of silica. No shells were observed, though plants were common.

PTERIDOSPERMEAE AND FILICALES	Frequency
Asterotheca micro-miltoni (*Artis*) (No. KP. 95)	2
Dactylotheca plumosa (*Artis*) (No. KP. 214)	5
Mariopteris *aff.* carnosa *Corsin*[1] (No. KP. 91)	1
,, ? nervosa (*Brongniart*) (No. KP. 111)	1
Neuropteris microphylla *Brongniart* (No. KP. 221)	2
,, pseudogigantea *Potonié* (No. KP. 97)	3
,, rarinervis *Bunbury* (No. KP. 90)	2
Pecopteris sp. (Nos. KP. 87-9)	2
Sphenopteris *aff.* douvillei *Zeiller* (No. KP. 108)	1
,, nummularia *Gutbier* (No. KP. 106)	3
,, sp. (No. KP. 110)	2
LYCOPODIALES	
Lepidodendron aculeatum *Sternberg* (No. KP. 226)	2
,, dichotomum *Zeiller* (No. KP. 195)	4
,, rimosum *Sternberg* (No. KP. 107)	2
Sigillaria? elongata *Brongniart* (Nos. KP. 208, 209)	1
,, laevigata *Brongniart* (No. KP. 223)	7
,, ? reniformis *Brongniart* (Nos. KP. 200, 201)	2
,, tessellata *Brongniart* (Nos. KP. 193, 194)	1
Lepidophyllum sp. (No. KP. 122)	1
EQUISETALES	
Annularia microphylla *Sauveur* (No. KP. 112)	3
Asterophyllites equisetiformis (*Schlotheim*) (Nos. KP. 113, 114)	3
Calamites goepperti *Ettingshausen* (No. KP. 121)	1
,, undulatus (*Sternberg*) (No. KP. 118)	1
Calamophloios sp. (No. KP. 121)	2
Calamitic cone (No. KP. 90)	2

[1] *Fide* Professor P. Bertrand.

CORDAITALES	Frequency
Cordaites principalis (*Germar*) (No. KP. 91)	10
Cordaianthus volkmanni (*Ettingshausen*) (No. KP. 189) ...	2

SEMINA INCERTAE SEDIS	
Carpolithus membranaceus (*Goeppert*) (No. KP. 206)	2
Cordaicarpus sp. (No. KP. 123)	2
Holcosperma sp. (No. KP. 102)	1
Samaropsis sp. (No. KP. 190)	4

Horizon : Roof of ' I ' Seam. At depth of 2148 ft. below O.D.

Remarks : The roof of the ' I ' Seam mainly consists of a sandy bind which merges into a micaceous sandstone roof. Locally there are a few softer areas of bind. It is in the latter that the few fossils were obtained from this horizon.

	Frequency
Lepidodendron sp. (No. KP. 187)	1
Sigillaria mammillaris *Brongniart* (No. KP. 186)	1
,, sp.	2
Calamites sp.	4
Carpolithus sp.	1

Analysis : It will be observed that the roof of the ' H ' Seam contains a number of species of *Sigillaria*, while that of the ' I ' Seam has yielded very few examples of the genera included under the Lycopodiales. The ' H ' Seam is also much richer in species than either ' F ' or ' I ' seams, and this especially applies to the Lycopodiales, Pterisdosperms and Filicales.

Characteristic plants of the ' H ' Seam are :—*Dactylotheca plumosa, Neuropteris pseudogigantea, Sphenopteris nummularia, Lepidodendron dichotomum, Sigillaria laevigata, Lepidodendron rimosum, Sigillaria tessellata, Annularia microphylla, Asterophyllites equisetiformis* and *Cordaites principalis*. Of these, the chief diagnostic forms are *Neuropteris pseudogigantea, Sphenopteris nummularia, Sigillaria laevigata, S. tessellata* and *Lepidodendron rimosum*. These are Yorkian forms. The presence of *Neuropteris rarinervis* and the absence of certain Yorkian forms indicate a position at the top of the Yorkian Stage.

' I ' Seam must be referred to a position towards the top of the Yorkian.

Locality : **Betteshanger Colliery.**

Horizon : ?

Remarks : The following specimens were collected by the writer at the tip-heap of the colliery. Although they may have been derived from ' F ' or ' I ' Seam, nine-tenths of the tipped material is from the ' H ' Seam. Some of the fossils are excellently preserved.

PTERIDOSPERMEAE AND FILICALES	Frequency
Alethopteris decurrens (*Artis*) (Nos. KP. 384, 676, 677, 678) ...	2
Aphlebia sp. (Nos. KP. 679, 680)	2
Asterotheca miltoni (*Artis*) (Nos. KP. 388, 617-641)	10

	Frequency
Asterotheca oreopteridia (*Schlotheim*) (Nos. KP. 718-727) ...	5
Corynepteris sp. (Nos. KP. 380, 642-9)	2
Crossotheca ? boulayi *Zeiller* (No. KP. 671)	1
Dactylotheca plumosa (*Artis*) (Nos. KP. 655, 656)	1
Diplotmema ? furcatum (*Brongniart*) (Nos. KP. 673, 681) ...	1
Mariopteris *aff.* muricata (*Schlotheim*) (Nos. KP. 534-547) ...	6
,, *aff.* sauveuri (*Brongniart*) (No. KP. 660)	1
,, *aff.* soubeirani *Zeiller* (No. KP. 853)	1
Neuropteris ? flexuosa *Sternberg* (Nos. KP. 854-856)	2
,, callosa *Jongmans & Gothan*[1] (Nos. KP. 383, 527-533)	3
,, heterophylla *forma* microphylla *Brongniart* (Nos. KP. 587-616)	6
,, obliqua *forma* morini *P. Bertrand*[1] (Nos. KP. 375, 507-512)	5
,, pseudogigantea *Potonié* (Nos. KP. 377, 513-526) ...	8
,, rarinervis *Bunbury* (No. KP. 724)	1
Odontopteris lindleyana *Sternberg* (Nos. KP. 851, 852) ...	1
? Renaulti schatzlarensis *Stur* (No. KP. 685)	1
Sphenopteris andreana *Roehl* (Nos. KP. 371, 667, 668) ...	2
,, dilatata *Lindley & Hutton* (Nos. KP. 386, 672) ...	4
,, nummularia *Gutbier* (Nos. KP. 376, 379, 686-717)	7
,, *cf.* striata *Gothan* (No. KP. 657)	1
LYCOPODIALES	
Lepidophloios acerosus *Lindley & Hutton* (No. KP. 389) ...	1
,, laricinus *Sternberg* (Nos. KP. 548-552)	4
Lepidostrobus brevifolius *Lesquereux* (No. KP. 574)	1
,, sp.	4
Sigillaria laevigata *Brongniart* (Nos. KP. 396-406)	6
Sigillariophyllum bicarinatum (*Lindley & Hutton*) (No. KP. 569)	6
Sigillariostrobus sp. (Nos. KP. 565-568)	1
SPHENOPHYLLALES	
Sphenophyllum cuneifolium (*Sternberg*) (Nos. KP. 385, 390, 495-506)	8
,, majus (*Bronn*) (Nos. KP. 563, 564)	1
,, myriophyllum *Crépin* (Nos. KP. 392, 559-561)	3
,, saxifragaefolium (*Sternberg*) (No. KP. 562) ...	1
EQUISETALES	
Annularia microphylla *Sauveur* (Nos. KP. 387, 414-420) ...	4
Asterophyllites equisetiformis (*Schlotheim*) (Nos. KP. 381, 746-762)	8
Calamites undulatus *Sternberg* (Nos. KP. 412, 413)	2
Calamostachys sp. (Nos. KP. 407-410)	4
CORDAITALES	
Cordaites ? principalis (*Germar*) (Nos. KP. 650-654)	4
Poacordaites gentilis *P. Bertrand*[1] (Nos. KP. 391, 683, 684) ...	1
SEMINA INCERTAE SEDIS	
Carpolithus sp. (Nos. KP. 674, 675)	3
Holcosperma sp. (No. KP. 682)	2

[1] *Fide* Professor P. Bertrand.

Synopsis of Species for Chief Horizons

(The figures in the columns represent frequency—see p. 45).

Colliery	Tilmanstone	Snowdown	Betteshanger			Chislet
Seam	Beresford	Millyard	F	H	I	No. 5
PTERIDOSPERMEAE AND FILICALES						
Alethopteris decurrens (*Artis*) ...	—	—	—	—	—	?4
,, lonchitica (*Schloth.*) ...	—	—	—	—	—	2
,, serli (*Brongt.*)	6	—	—	—	—	—
,, valida (*Boulay*) ...	—	—	—	—	—	1
Aphlebia gigantea *Zeiller*	—	—	—	—	—	2
Asterotheca micro-miltoni (*Artis*) ...	5	1	—	2	—	—
Dactylotheca plumosa (*Artis*) ...	—	—	—	5	—	3
Eupecopteris sp.	4	—	—	—	—	—
Linopteris obliqua (*Bunbury*) ...	—	4	1	—	—	—
Mariopteris *aff.* carnosa *Corsin* ...	—	—	—	1	—	1
,, jacquoti *Zeiller* ...	—	—	—	—	—	?1
,, nervosa (*Brongt.*) ...	4	—	—	?1	—	?2
Neuropteris callosa *J. & G.*	—	—	—	—	—	5
,, flexuosa (*Sternb.*) ...	3	—	—	—	—	—
,, heterophylla *Brongt.* ...	—	3	—	—	—	10
,, microphylla *Brongt.* ...	—	—	—	2	—	—
,, obliqua *Brongt.*... ...	—	—	—	—	—	5
,, pseudogigantea *Pot.* ...	—	—	—	3	—	6
,, rarinervis *Bunbury* ...	3	—	—	2	—	—
,, scheuchzeri *Hof.* ...	10	—	—	—	—	—
,, tenuifolia (*Schloth.*) ...	—	—	—	1	—	10
Odontopteris lindleyana *Sternb.* ...	1	—	—	—	—	—
Sphenopteris dilatata *L. & H.* ...	—	—	—	—	—	3
,, neuropteroides *Boul.*	4	—	—	—	—	—
,, nummularia *Gutb.* ...	—	—	—	3	—	—
,, ? striata *Gothan* ...	—	1	—	—	—	—
LYCOPODIALES						
Bothrodendron minutifolium (*Boul.*)	—	—	—	—	—	7
Lepidodendron aculeatum *Sternb.* ...	—	2	—	1	—	1
,, acutum (*Presl*) ...	—	1	—	—	—	—
,, dichotomum *Sternb.*	—	3	—	4	—	—
,, jaraczewski *Zeiller*	—	?1	—	—	—	—
,, obovatum *Sternb.* ...	—	2	—	—	—	—
,, rimosum *Sternb.* ...	—	2	—	2	—	—
Lepidophloios acerosus *L. & H.* ...	—	—	—	—	—	3
Sigillaria ? elongata *Brongt.*... ...	—	—	—	1	—	—
,, laevigata *Brongt.*	—	—	—	7	—	—
,, mammillaris *Brongt.* ...	—	—	—	—	1	—
,, ? reniformis *Brongt.* ...	—	—	—	2	—	—
,, tessellata *Brongt.*	—	—	—	1	—	2
Lepidostrobus brevifolius (*Lesqx.*) ...	—	3	—	—	1	—
,, lanceolatus (*L. & H.*) ...	1	—	1	—	—	—
,, goodei *Jongmans*	—	3	—	—	—	—
,, triangularis (*Zeiller*) ...	—	1	—	—	—	—
Stigmaria ficoides (*Sternb.*)... ...	—	—	—	4	—	—
,, minuta (*Goepp.*)	—	—	—	—	—	5
Sigillariophyllum bicarinatum (*L. & H.*) ...	1	—	—	—	—	—

Colliery	Tilmanstone	Snowdown	Betteshanger			Chislet
Seam	Beresford	Millyard	F	H	I	No. 5
EQUISETALES						
Annularia microphylla *Sauv.* ...	—	—	—	3	—	3
,, galioides *L. & H.*	?1	—	—	—	—	5
,, radiata *Brongt.*	—	—	—	—	—	3
,, sphenophylloides (*Zenk.*) ...	3	1	—	—	—	4
,, stellata (*Schlotheim*) ...	3	—	—	—	—	—
Asterophyllites charaeformis (*Sternb.*) ...	—	—	—	—	—	10
,, equisetiformis (*Schloth.*) ...	—	—	—	3	—	—
,, grandis (*Sternb.*)	—	—	—	—	—	5
Calamites carinatus *Sternb.* ...	—	3	—	—	—	8
,, goepperti *Ett.*	—	—	—	1	—	4
,, sachsei *Stur*	—	—	—	—	—	1
,, suckowi *Brongt.*	—	4	—	—	—	6
,, undulatus *Sternb.* ...	—	—	—	1	—	10
SPHENOPHYLLALES						
Sphenophyllum cuneifolium (*Sternb.*)	—	—	—	—	—	10
,, emarginatum *Brongt.*	5	—	—	—	—	—
,, majus (*Bronn*) ...	1	1	1	—	—	—
,, myriophyllum *Crépin*	—	—	—	—	—	6
,, saxifragaefolium (*Sternb.*) ...	—	—	—	—	—	6
CORDAITALES						
Cordaites principalis (*Germ.*) ...	—	—	—	10	—	—
,, sp.	1	1	—	—	—	1
Cordaianthus volkmanni (*Ett.*) ...	—	—	—	2	—	—
SEMINA INCERTAE SEDIS						
Carpolithus membranaceus (*Goepp.*)	—	—	—	2	—	—
Cornucarpus arberi (*Kidst. MS.*) *Crookall*	1	—	—	—	—	—
Holcosperma fimbriatum *Crookall* ...	—	1	—	—	—	—
Trigonocarpus noeggerathi (*Sternb.*)	1	—	—	—	—	—
,, parkinsoni *Brongt.*	—	—	—	—	—	1
Samaropsis reniformis (*Gein.*) ...	—	1	—	—	—	—

Descriptions of New Species

Cornucarpus arberi sp. nov.

Plate VI, fig. 10

In 1909, the late Dr. E. A. N. Arber[1] figured, but did not describe, a seed from the Waldershare Series of the Waldershare Park Boring, about 6 miles north-west of Dover, which was found at a depth of 2425 ft. from the surface. This he indentified with

[1] Arber, E. A. N., 'On the Fossil Plants of the Waldershare and Fredville Series of the Kent Coalfield,' *Quart. Journ. Geol. Soc.*, 1909, vol. lxv, pl. i, fig, 5.

Lindley and Hutton's *Cardiocarpon acutum*[1] from the Bensham Seam, Jarrow Colliery, Newcastle and Durham Coalfield, and also compared with the seeds figured by Brongniart[2] in 1828 as occurring in association with fronds of the Pteridosperm *Sphenopteris* (*Eremopteris*) *artemisaefolia* Sternberg.[3] In both British coalfields the seeds occur in groups. *Samaropsis* seeds are usually found in groups on the Coal Measures shales, this being due to their having been borne in spikes.

Arber's identification of his seeds with *C. acutum* was in error. There were important differences in shape and in the apical and basal regions, and the two species may be contrasted as follows:

	C. acutum L. & H.	Arber's seeds
Shape	oval	urn-shaped
Base	occasionally with a point, generally rounded or even emarginate	always prolonged into a stalk-like extension
Apex	with a single, short, median point	with two spreading hornlike points
Associated plants	always associated with *Eremopteris artemisaefolia*	associated with Cordaites: never with *E. artemisaefolia*
Horizon (frequency represented by numbers 1-10)	Radstockian Stage — 0 Staffordian ,, — 0 Yorkian ,, — 5 Lanarkian ,, — ?	Radstockian Stage — 1 Staffordian ,, — 5 Yorkian ,, — 1 Lanarkian ,, — 0

With Brongniart's figures (showing three whole seeds and part of a fourth) there is more similarity, but the Kent specimens cannot be identified with Brongniart's as the latter are not pedicillate and the apical points are not spread out. The latter feature, however, may be related to the maturity of the fructification. The three sets of seeds referred to are regarded by the writer as representing three distinct species.

In 1914, Arber[4] figured a further specimen from a depth of 2000 ft. in the Goodnestone Boring, Kent (preserved in the Sedgwick Museum, Cambridge—No. 2230, Carbon. Plant Collection), but made no reference to his previous figure. He here instituted a new genus for the seed, namely *Cornucarpus*, the distinguishing features being the triangular shape and the well-marked apical horns on the wing.

[1] Lindley, J., and W. Hutton, 'The Fossil Flora of Great Britain,' *London*, 1831-1837, vol. i, pl. 76, p. 209.

[2] Brongniart, A., 'Histoire des Végétaux Fossiles,' *Paris*, 1828, pl. 46.

[3] Sternberg, C. von, *Essai flore monde prim.*, vol. i, fasc. iv, p. xv, pl. lvi, fig. I; vol. ii' fasc. v-vi, p. 58, 1833 (including vars. *tripartita*, *dichotoma* and *minor*).

[4] Arber, E. A. N., 'A Revision of the Seed Impressions of the British Coal Measures, *Annals of Botany*, vol. xxviii, no. cix, 1914, pl. vi, fig. 14, text-fig. 2, p. 97.

He again confused the fossil with Lindley and Hutton's *C. acutum.*[1]

In 1914[2] Kidston, in recording *Cardiocarpon acutum* (as *Samaropsis*) from the Staffordshire Coalfield, observed that if Arber's figure of his specimen " is an accurate representation of the fossils, then his seeds must belong to another species," while in 1919[3] he re-named (but did not describe or figure) the Kent seeds as *Samaropsis arberi*. He photographed specimens from a depth of 2242 ft., Staffordian Stage, in the boring at Tower Brickworks, Folkestone, but left no diagnosis of the species. Further examples having recently been collected from the Kent Coalfield, the seed is here described, Kidston's specific name being adopted.

The genus *Samaropsis*, however, was instituted for seeds of a more oval contour and lacking apical horns. The two diverging apical horns of Arber's seeds are sufficiently distinctive to deserve generic distinction. Arber's term *Cornucarpus* has recently been accepted by Professor T. G. Halle[4] who described similar forms from the Permo-Carboniferous of Central Shansi, China. The genotype is Lindley and Hutton's *Cardiocarpon acutum*. Professor Halle would place all seeds of the *Samaropsis* type which are bicornute in Arber's genus, but excluding those which merely bear an apical notch (e.g. *Samaropsis emarginata*), and gives the following diagnosis: " Platyspermic seeds, with or without wings, provided at the apex with two acute projecting horns, which are at least as long as they are broad or more often longer." The Kent seeds here described should therefore be named *Cornucarpus arberi* (Kidston MS.) Crookall.

Complete specimens, which are urn-shaped, are 1.2 cm. long (including the base and the two horn-like extensions of the wing which form the apex) and 4 to 5 mm. wide. There is a prominent median longitudinal ridge on most examples. The nucule is situated rather below the centre of the seed and has been observed in two specimens only[5] (and even here the form of the apical region cannot be satisfactorily made out). Arber apparently saw no specimens in which the nucule was present: he therefore described his seeds as ' not winged.' The wing surrounds the nucule and is about 0.75 mm. broad at the base, widening out upwards and attaining a breadth of about 1.5 mm. near the apex of the nucule, beyond which it expands into the two characteristic diverging horn-like terminations

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[1] As was first pointed out by Professor Duns (*Proc. Roy. Soc. Edin.*, 1871-2, p. 692), the true *Samaropsis* (*Cardiocarpon*) *acuta* of Lindley and Hutton is often found associated with the leaves designated *Eremopteris artemisaefolia* (Sternberg). Kidston (' Fossil Plants of the Carboniferous Rocks of Great Britain ' (*Mem. Geol. Surv.*, Palaeontology), vol. ii, 1923-5, p. 410) observed, " The constant occurrence of *Samaropsis acuta* L. & H. sp. with *Eremopteris artemisaefolia* points most strongly to the probability of these small seeds being those of that plant. It is almost impossible to collect *Eremopteris artemisaefolia* without also finding *Samaropsis acuta* in the same bed. Few specimens of *Eremopteris artemisaefolia* fail to show some examples of it on the same slab."

[2] Kidston, R., ' On the Fossil Flora of the Staffordshire Coalfields,' *Trans. Roy. Soc. Edin.*, vol. l, pt. i, No. 5, p. 156.

[3] Kidston, R., ' Summary of Progress ' for 1918 (*Mem. Geol. Surv.*), 1919, App. II, p. 47.

[4] Halle, T. G., ' Palaeozoic Plants from Central Shansi,' *Palaeontologia Sinica*, Ser. A, vol. ii, fasc. I, 1927, p. 199.

[5] *E.g.* No. KP. 17, Geological Survey of England, from the Beresford Seam, Tilmanstone Colliery.

of the wing. The base of the seed is prolonged into a tapering pedicel-like stalk.

In a specimen of *C. arberi* (No. Pe. 1455) from the Tower Brickworks Boring the seeds are adjacent to a small stem (about 1.5 mm. broad) and one seed appears to be attached to this stem. Otherwise, all known specimens are detached. Arber gave the length of the specimens as 6-10 mm.; but recently collected examples are rather larger. The average length is 8 or 9 mm.

C. arberi is characterised by the two widely diverging apical 'horns' formed by the wing and by the tapering stalk-like base. Lesquereux' *Samaropsis bicornuta*, originally figured[1] as *Ptilocarpus* but later[2] merged in *Cardiocarpus* (a genus now reserved for structurally preserved seeds), should now be referred to *Cornucarpus*. It also shows these features, but there are considerable differences between the two species, and *C. bicornutus* is unknown from Britain. A further slight similarity refers to the fact that in both forms the nucule easily became detached. The species may be contrasted as follows:

	C. arberi	*C. bicornutus*
Size and shape	length — 12 mm. width — 4-5 mm. *i.e.* broader in proportion to length	length — 19 mm. width — 5.5 mm.
Nucule	below centre of seed	above centre of seed
Median longitudinal ridge	present	absent
Apical 'horns'	slightly curved	more curved

As Arber confused *C. arberi* with Lindley and Hutton's *Cardiocarpon acutum*, he gave its distribution[3] as "Transition Coal Measures of Kent,[4] the Middle Coal Measures of Leicestershire and the Lower Coal Measures of the Newcastle, Ayrshire and Lanarkshire Coalfields." Actually, *C. arberi* appears to be confined to the Kent Coalfield, where it is found only in Radstockian and Staffordian rocks. On the grounds of association, I believe the seed to belong to a species of *Cordaites* (whereas *C. acutum* no doubt belongs to the Pteridosperm *Eremopteris artemisaefolia*).

The following is the complete distribution of *C. arberi*:—

RADSTOCKIAN STAGE

Horizon: Beresford Seam (Farrington Group).
Locality: Tilmanstone Colliery.
Collection: Geological Survey of England, No. KP. 17—R. Crookall.

[1] Lesquereux, L., 'Coal Flora of the Carboniferous Formation in Pennsylvania,' vol. i, 1879, Expl. to pl. lxxxv, fig. 5I, 5Ia.
[2] Lesquereux, L., *ibid.*, Text, 1880, p. 565.
[3] Arber, E. A. N., *op. cit.*, 1914, p. 97.
[4] Arber, E. A. N., *ibid.*; he omits the Middle Coal Measures of Kent, though the specimen he figures (fig. 14) is cited as coming from that horizon.

STAFFORDIAN STAGE

Horizon: At a depth of 2425 feet (Waldershare Series).
Locality: Waldershare Park Boring, 6 miles N.W. of Dover.
Collection: Sedgwick Museum, Cambridge, Carbon. Plant Collection—E. A. N. Arber.

Horizon: At a depth of 2242 feet.
Locality: Tower Brickworks Boring, Folkestone.
Collection: Geological Survey of England, No. Pe. 1455, 1456—R. Kidston.

Horizon: At a depth of 2819-2830 feet.
Locality: Tilmanstone Colliery, No. 3 Shaft.
Collection: Geological Survey of England, No. KP. 18—R. Crookall.

Horizon: At a depth of 2830-2834 feet.
Locality: Tilmanstone Colliery, No. 3 Shaft.
Collection: Geological Survey of England, No. KP. 22—R. Crookall.

Horizon: At a depth of between 2966 and 2970 feet.
Locality: Tilmanstone Colliery (No. 3 Shaft).
Collection: Geological Survey of England, No. KP. 21—R. Crookall.

Horizon: At a depth of 2000 feet.[1]
Locality: Goodnestone Boring.
Collection: Sedgwick Museum, Cambridge, Carbon. Plant Collection, No. 2230—E. A. N. Arber.

Holcosperma fimbriatum sp. nov.

Plate VI, fig. 1.

This species is represented by a single specimen which was obtained from the Millyard Seam of Snowdown Colliery.

The seed is almost complete and measures 13 mm. in length by 4 mm. in maximum breadth (excluding the fringe to be described). It is elliptical, the broadest point being in the middle and the margins tapering gradually and symmetrically towards both base and apex. The base is only partially preserved, but was evidently bluntly pointed (see Plate VI, fig. 1, where the specimen is reproduced at a magnification of 5 times). At the tapering apex there is a micropyle about 2 mm. long. On the surface shown there is a strong longitudinal ridge down the centre of the seed and, on each side of this, half-way to the margin, is another, less prominent, ridge. On account of these ridges the seed is referred to the genus *Holcosperma* Nathorst (who erroneously spelled the word '*Holcospermum*'). Between the ridges the surface is slightly rugose.

The characteristic feature of this fossil consists in a fringe of hair-like processes which surround it, extending over the matrix for a distance of from 2 to 2.5 mm. At first sight these hairs might be regarded as the remains of a 'wing' due to a soft outer envelope which became crushed in fossilisation and which subsequently

[1] According to Arber this level falls within the Yorkian Stage, but the writer places it in the Staffordian.

decayed at intervals. The regularity of the hairs, however, precludes this interpretation : they were evidently normal features of the seed. As will be seen from the photograph (especially on the left hand side) they are found along the micropyle as well as along the margin of the body of the seed, forming almost a right angle with it. In some cases the hairs bifurcate at a point about a third or half way from their base. *Holcosperma fimbriatum* could not be confused with any seed known from Britain, the fringe of hairs alone being distinctive.

The following is the complete distribution of *H. fimbriatum* :—

STAFFORDIAN STAGE

Horizon : Millyard Seam.
Locality : Snowdown Colliery, Nonnington, near Dover.
Collected : W. Dewar.
Collection : Museum of Practical Geology, No. 49370 (Type).

SUMMARY OF STRATIGRAPHICAL RESULTS

The following are the chief palaeobotanical results obtained from the present revision of the pits working :—

CHISLET COLLIERY :

(1) No. 5 Seam—Yorkian Stage.
Assise d'Anzin of North of France (P. Bertrand).

(2) Main West Drift—in Yorkian throughout.
Assise d'Anzin of North of France (P. Bertrand).

(3) Seam at 1464½ ft. below O.D. in Main West Drift—doubtfully equivalent to No. 5 Seam.

SNOWDOWN COLLIERY :

Millyard Seam—Staffordian Stage.

TILMANSTONE COLLIERY :

(1) No. 1 Shaft, Beresford Seam—low in Radstockian Stage.
Top of Assise de Bruay of North of France (P. Bertrand).

(2) No. 3 Shaft—Staffordian Stage.

(3) No. 3 Shaft borehole—down to 3384 ft. : probably Staffordian Stage ; below 3384 ft. : probably top of Yorkian. Both shaft and borehole are to be correlated with the Assise de Bruay of North of France (P. Bertrand).

BETTESHANGER COLLIERY :

(1) 'F' Seam—Staffordian Stage.
Assise de Bruay of North France (P. Bertrand).

(2) 'H' Seam—top of Yorkian Stage.
Assise de Bruay of North France (P. Bertrand).

(3) 'I' Seam —towards top of Yorkian Stage.

General Observations

(1) The general conclusions arrived at by Arber, Kidston and Bolton, and particularly by the first-named, are justified in the present work. The Kent Coal Measures include representatives of the lower Radstockian (Farrington = Keele Group), the Staffordian and the Yorkian Stages (see Comparative Table on p. 66). It

COMPARATIVE TABLE OF THE COAL MEASURES OF KENT.

BOLTON'S DIVISIONS	LITHOLOGY	PALAEONTOLOGICAL DIVISIONS
		RADSTOCKIAN STAGE (FARRINGTON GROUP) 550 FT.
UPPER SERIES ABOUT 2200 FT.	THICK SANDSTONES WITH SUBORDINATE BANDS OF SHALE. MAINLY THIN COALS. BERESFORD SEAM NEAR TOP; MILLYARD SEAM NEAR BOTTOM.	STAFFORDIAN STAGE 1600 FT.
LOWER SERIES ABOUT 600 FT.	CHIEFLY SHALES AND FIRECLAYS MANY COALS, SEVERAL OF WHICH ARE THICK LOCALLY Nº 5 SEAM OF CHISLET ABOUT MIDDLE OF DIVISION	YORKIAN STAGE 650 FT.

should be pointed out, however, that the writer places the base of the Radstockian and that of the Staffordian at levels lower than those assigned by others. No Lanarkian flora has yet been recognised, and Dr. Walcot Gibson has pointed out that the absence of *Carbonicola robusta* from the cores hitherto examined also suggests

the absence of true Lower Coal Measures. Rocks equivalent to the highest British Coal Measures, namely, the Radstock Series of the Somerset Coalfield (representing the type of Kidston's Radstock Group) are unrecognised in Kent. It is not impossible, however, that they occur in the unexplored strata towards the southern boundary of the coalfield, beneath the English Channel.

(2) Below is given, in tabular form, a comparison of the palaeobotanical divisions recognised in the southern British coalfields.

Stage	Radstockian		Staffordian	Yorkian	Lanarkian
Group	Radstock	Farrington			
South Wales ...	?	present	present	present	present[1]
Forest of Dean ...	absent	present[2]	present	absent	absent
Somerset and Bristol	present	present	present	present	present[3]
Kent	absent	present	present	present	absent

(3) With regard to the neighbouring Continental coalfields, a comparison of the Kent floras[4] with those of the Pas de Calais[5] and the Nord de France (Valenciennes)[6] shows general though not complete agreement.[7] We have no palaeobotanical evidence for Stephanian rocks in Britain.[8, 9, 10]

[1] See R. Crookall, *op. cit.*, 1931, pp. 1-34.

[2] See R. Crookall, *op. cit.*, 1930.

[3] See R. Crookall, 'Coal Measures Terminology,' *The Naturalist*, 1932, p. 43.

[4] See Arber, *op. cit.*, 1909, pp. 35, 36.

[5] Zeiller, R., 'Sur les Subdivisions du Westphalien du Nord de la France d'après les Caractères de la Flore,' *Bull. Soc. Géol. France*, sér. 3, vol. xxii, 1894, pp. 490, 495.

[6] Zeiller, R., 'Flore Fossile du Bassin houiller de Valenciennes,' Text, 1888, Atlas, 1886, *Études Gîtes Minéraux de la France.*

[7] See also P. Bertrand, 1913, 'Sur la présence des *Linopteris* dans les zones inférieure et moyenne de bassin houiller du Nord de la France,' *Ann. Soc. Géol. du Nord*, vol. xlii, p. 338; 1914, 'Les Zones Végétales du terrain houiller du Nord de la France, etc.,' *ibid.*, vol. xliii, p. 210; 1918, 'Les Grandes Divisions Paléontologiques du Bassin de la Loire,' *Comptes rendus*, vol. 167, p. 689; 1919, 'Sur la Flore de Bassin Houiller de Lyons,' *ibid.*, vol. 168, p. 174; 1919, 'Les Zones Végétales du Terrain Houiller du Nord de la France,' *ibid.*, vol. 168, p. 780; 1920, 'Succession normale des Flores houillères dans le Bassin Houiller du Gard,' *ibid.*, vol. 170, p. 331; 1922, 'Succession régulière des Zones Végétales dans les Bassins Houillers Français, *Compte rendu du Xiii e Congrès géologique International*, 1922, p. 599; 1922, 'Sur les Flores Houillères de la Sarre,' *Comptes rendus des séances de l'Académie des Sciences*, vol. 175, p. 770; 1926, 'Les Gisements a *Mixoneura* dans la région de Saint-Gervais-Chamonix,' *Bull. Soc. Géol. de France*, vol. xxvi, p. 381; 1928, 'Stratigraphie du Westphalien et du Stéphanien dans les différents bassins houillers Français,' *Congrès de Stratigraphie Carbonifère, Heerlen*, 1927, Liége, 1928, p. 93; 1928, 'Valeur des Flores pour la charactérisation des différentes assises du terrain houiller,' etc., *ibid.*, p. 103; P. Bertrand and P. Corsin, 1927, 'Observations sur le *Neuropteris scheuchzeri* Hofmann,' *Ann. de la Soc. Géol. du Nord*, vol. lii, p. 155; 1931, 'Excursion dans les houillères Anglaises,' *ibid.*, vol. lv, p. 207, and P. Corsin, 1932, 'Guide Paléontologique dans le Terrain Houiller du Nord de la France,' *Travaux et Mémoires de l'Université de Lille*, Fasc. No. 5.

[8] Gibson, W., *op. cit.*, 1927, p. 52, and E. Dix and A. E. Trueman, 'Some Non-marine Lamellibranchs from the Upper Part of the Coal Measures,' *Quart. Journ. Geol. Soc.*, vol. lxxxvii, 1931, p. 196.

[9] This was first shown by Zeiller (in R. Kidston, 'On the Fossil Flora of the Radstock Series of the Somerset and Bristol Coalfield,' *Trans. Roy. Soc. Edin.*, vol. xxxiii, 1888, p. 335). See also C. Grand 'Eury in *Trans. Inst. Min. Eng.*, vol. xxv, 1902-3, p. 392, and R. Zeiller, *ibid.*, p. 389.

[10] Arber, E. A. N., *op. cit.*, 1916, and R. Crookall, 'Correlation of the British and French Upper Coal Measures,' 'Summary of Progress' for 1930, Part iii (*Mem. Geol. Surv.*), 1931, pp. 62-69.

(4) Dr. H. Bolton[1] recorded the occurrence of "portions of woody tissue with the structure well preserved" in the Coal Measures of Kent similar to those discovered by him at Staplehill, near Bristol.[2, 3] In view of this record, the writer sought for petrified remains at the four pits working, but without success. The matter should, however, be borne in mind in future investigations of the Kent Coal Measures as the flora brought to light would be of considerable importance.[4] With the exception of the Bristol specimens, which belong to the Staffordian Stage, almost all the petrified plants of the British Coal Measures are from beds of Lanarkian age. Few petrifactions are known from the Yorkian and none from the Radstockian Stage. The well-known petrifactions of France are from the Permo-Carboniferous, and any specimens found in Kent would constitute a link between the earlier British and the later French remains.

[1] Bolton, H., 'The Fauna and Stratigraphy of the Kent Coalfield,' *Trans. Inst. Mining Eng.*, vol. xlix, 1915, p. 649.

[2] Lillie, D. G., 'On Petrified Plant Remains from the Upper Coal Measures of Bristol,' *Proc. Camb. Phil. Soc.*, vol. xv, 1910, p. 411; *Geol. Mag.*, vol. vii, 1910, p. 411.

[3] Crookall, R., 'On a New Species of *Sutcliffia*,' 'Summary of Progress' for 1926 (*Mem. Geol. Surv.*), 1927, pp. 161-167; 'Petrified Plants from the Pennant Rock,' *ibid.*, for 1930, Part iii, 1931, pp. 52-60. A further account is to be published shortly.

[4] Since the above was written, Mr. J. E. Jones, the Manager of the Chislet Colliery, has sent in a specimen representing a fragment of petrified stem from the conglomerate roof of the No. 21 level of the pit. This was sectioned and proved to be *Dadoxylon*. This is the first record of an identified petrifaction from the Coal Measures of Kent.

Explanation of Plate V

Fig. 1. *Sphenopteris nummularia* Gutbier × 1 (No. 50543).
Horizon: 'H' Seam (Yorkian Stage).
Locality: Betteshanger Colliery, near Dover.

Fig. 2. *Neuropteris obliqua* Brongniart × 9/10 (No. 50544).
Horizon: No. 5 Seam (Yorkian Stage).
Locality: Chislet Colliery, near Canterbury.

Fig. 3. *Lepidodendron obovatum* Sternberg × 1 (No. 50545).
Horizon: ? Millyard Seam.
Locality: Snowdown Colliery, near Dover.

Fig. 4. *Neuropteris pseudogigantea* Potonié × 1 (No. 50546).
Horizon: 'H' Seam (Yorkian Stage).
Locality: Betteshanger Colliery, near Dover.

Fig. 5. *Annularia radiata* Brongniart × 1 (No. 50547).
Horizon: No. 5 Seam (Yorkian Stage).
Locality: Chislet Colliery, near Canterbury.

Fig. 6. *Alethopteris valida* Boulay × 1 (No. 50548).
Horizon: No. 5 Seam (Yorkian Stage).
Locality: Chislet Colliery, near Canterbury.

Fig. 7. *Dactylotheca plumosa* (Artis) × 1 (No. 50549).
Horizon: 'H' Seam (Yorkian Stage).
Locality: Betteshanger Colliery, near Dover.

Fig. 8. *Sphenopteris dilatata* Lindley & Hutton × 1 (No. 50550).
Horizon: ?
Locality: tip-heap at Betteshanger Colliery, near Dover.

Fig. 9. *Lepidophloios laricinus* Sternberg × 1 (No. 50551).
Horizon: ?
Locality: tip-heap at Betteshanger Colliery, near Dover.

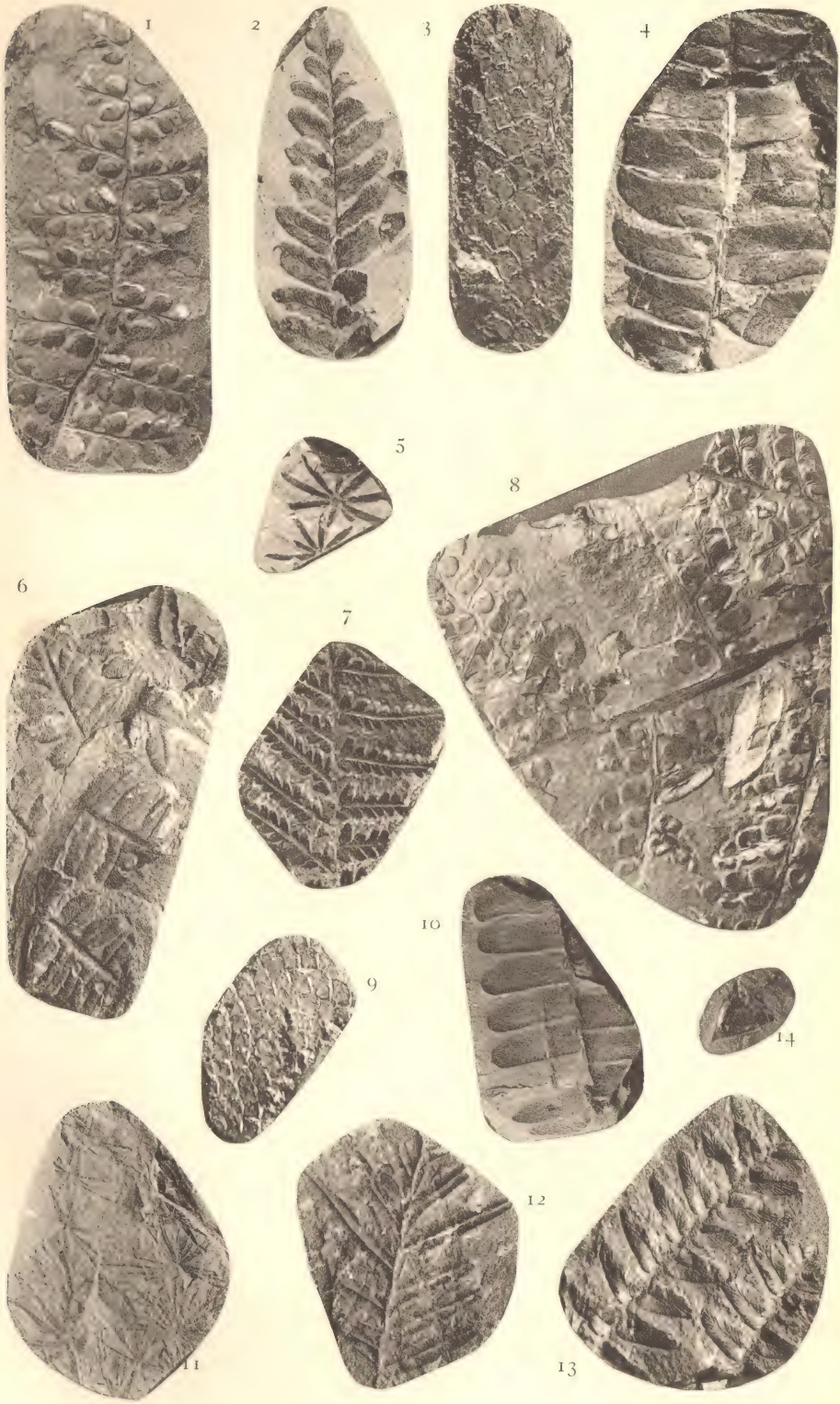
Fig. 10. *Linopteris obliqua* (Bunbury) × 1 (No. 50552).
Horizon: Millyard Seam (Staffordian Stage).
Locality: Snowdown Colliery, near Dover.

Fig. 11. *Asterophyllites equisetiformis* (Schlotheim) × 1 (No. 50553).
Horizon: ?
Locality: tip-heap at Betteshanger Colliery, near Dover.

Fig. 12. *Alethopteris lonchitica* (Schlotheim) × 1 (No. 50554).
Horizon: No. 5 Seam (Yorkian Stage).
Locality: Chislet Colliery, near Canterbury.

Fig. 13. *Neuropteris microphylla* Brongniart × 1 (No. 50555).
Horizon: 'H' Seam (Yorkian Stage).
Locality: Betteshanger Colliery, near Dover.

Fig. 14. *Lepidostrobus goodei* Jongmans × 1 (No. 50556).
Horizon: Millyard Seam (Staffordian Stage).
Locality: Snowdown Colliery, near Dover.



FOSSIL PLANTS: KENT COALFIELD.

FOSSIL PLANTS: KENT COALFIELD.

Explanation of Plate VI

Fig. 1. *Holcosperma fimbriatum* Crookall × 5 (No. 49370).
Horizon: Millyard Seam (Staffordian Stage).
Locality: Snowdown Colliery, near Dover.

Fig. 2. *Sphenopteris dilatata* Lindley & Hutton × 1 (No. 50557).
Horizon: No. 5 Seam (Yorkian Stage).
Locality: Chislet Colliery, near Canterbury.

Fig. 3. *Annularia sphenophylloides* (Zenker) × 1 (No. 50558).
Horizon: Beresford Seam (Radstockian Stage).
Locality: Tilmanstone Colliery, near Dover.

Fig. 4. *Alethopteris serli* (Brongniart) × 1 (No. 50559).
Horizon: Beresford Seam (Radstockian Stage).
Locality: Tilmanstone Colliery, near Dover.

Fig. 5. *Sphenophyllum myriophyllum* Crépin × 1 (No. 50560).
Horizon: No. 5 Seam (Yorkian Stage).
Locality: Chislet Colliery, near Canterbury.

Fig. 6. *Mariopteris nervosa* (Brongniart) × 1 (No. 50561).
Horizon: Beresford Seam (Radstockian Stage).
Locality: Tilmanstone Colliery, near Dover.

Fig. 7. *Neuropteris callosa* Jongmans & Gothan × 1 (No. 50562).
Horizon: ?
Locality: tip-heap at Betteshanger Colliery, near Dover.

Fig. 8. *Eupecopteris bucklandi* (Brongniart) × 2 (No. 47515).
Horizon: at depth of 2950-5 ft. (Staffordian Stage).
Locality: Boring at Tower Brickworks, Folkestone.

Fig. 9. *Bothrodendron minutifolium* (Boulay) × 1 (No. 50563).
Horizon: No. 5 Seam (Yorkian Stage).
Locality: Chislet Colliery, near Canterbury.

Fig. 10. *Cornucarpus arberi* (Kidston MS.) Crookall × 2 (No. 50570).
Horizon: at depth of 2242 ft. (Staffordian Stage).
Locality: Boring at Tower Brickworks, Folkestone.

Explanation of Plate VII

Fig. 1. *Sphenophyllum myriophyllum* Crépin × 1 (No. 50564).
Horizon: No. 5 Seam (Yorkian Stage).
Locality: Chislet Colliery, near Canterbury.

Fig. 2. *Sigillaria tessellata* Brongniart × 1 (No. 50565).
Horizon: No. 5 Seam (Yorkian Stage).
Locality: Chislet Colliery, near Canterbury.

Fig. 3. *Sphenophyllum saxifragaefolium* (Sternberg) × 1 (No. 50619)
Horizon: No. 5 Seam (Yorkian Stage).
Locality: Chislet Colliery, near Canterbury.

Fig. 4. *Neuropteris heterophylla* Brongniart × 1 (No. 50566).
Horizon: No. 5 Seam (Yorkian Stage).
Locality: Chislet Colliery, near Canterbury.

Fig. 5. *Bothrodendron minutifolium* (Boulay) × 1 (No. 50567).
Horizon: No. 5 Seam (Yorkian Stage).
Locality: Chislet Colliery, near Canterbury.

Fig. 6. *Sphenophyllum cuneifolium* (Sternberg) × 1 (No. 50568).
Horizon: ?
Locality: tip-heap at Betteshanger Colliery, near Dover.

Fig. 7. *Neuropteris rarinervis* Bunbury × 1 (No. 50569).
Horizon: Beresford Seam (Radstockian Stage).
Locality: Tilmanstone Colliery, near Dover.

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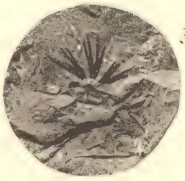
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FOSSIL PLANTS : KENT COALFIELD.

II.—CONTRIBUTIONS TO THE GEOLOGY OF THE KENT COALFIELD

(III). NOTES ON THE FAUNA OF THE COAL MEASURES OF KENT

BY

C. J. STUBBLEFIELD, PH.D., A.R.C.SC.

THE NON-MARINE FAUNA

COLLECTIONS of lamellibranchs were examined by Professor A. E. Trueman from Betteshanger, Snowdown and Tilmanstone Collieries, and identifications are given on pp. 76-7. Professor Trueman remarked that the collection included " four species which are not identical with any named forms," these he indicated in his list by numbers. He continued " I do not think it possible to draw any reliable conclusions from these shells until I have seen more material from this area. The beds are clearly within the *Anthraconauta* [*Anthracomya*] *phillipsi* and *A. tenuis* Zones, chiefly I think in the lower part of the *A. tenuis* Zone."

Subsequently Professor Trueman[1] has published the statement that while he agrees " that part of the Kent Coal Measures may be referred to these upper zones, the occurrence of species of Carbonicola and Naiadites affords evidence for the existence of at least part of the Pulchra Zone (see Bolton, 1915, pl. ix)."[2]

The occurrences of *Carbonicola* recorded by Dr. Bolton (*op.cit.*) were *Carbonicola acuta* from a depth of 1984 ft. at Stodmarsh boring, *i.e.* from within 100 ft. of the junction of the Coal Measures and the Carboniferous Limestone; and *Carbonicola sp.*, recorded from within 60 ft. of this junction at Woodnesborough. Both these finds are clearly low in the local stratigraphical succession and may well lie in the Zone of *A. pulchra*; but of the *Naiadites* records, the most noteworthy are those at Mattice Hill where Bolton (*op. cit.*, p. 682) recorded "*Naiadites carinata* Sowerby," from depths of 1263 to 1271 ft. and 1346 to 1366 ft. and doubtfully from 1748 ft. These horizons are respectively about 100 ft. above, about the same level as, and about 400 ft. below the Mattice Hill marine band.

Through the courtesy of Dr. F. S. Wallis of the Bristol Museum and Art Gallery, I have been privileged to examine the specimen figured by Bolton as *Naiadites carinata* from about the marine band level (1366 ft.) at Mattice Hill. This specimen would nowadays be named *Naiadites* cf. *producta* (Brown) and forms allied to this have

[1] ' A suggested Correlation of the Coal Measures of England and Wales,' *Proc. S. Wales Inst. Eng.*, vol. xlix, 1933, p. 87.

[2] Bolton, H., ' The Fauna and Stratigraphy of the Kent Coalfield,' *Trans. Inst. Mining Eng.*, vol. xlix, pt. 4, 1915, pl. ix, figs. 10, 18.

been collected from 350 ft. above the base of the *A. phillipsi* Zone of Yorkshire as well as from lower levels.[1] This new determination has been confirmed by Professor Trueman. It appears therefore that the *Naiadites* evidence for the presence of the Zone of *A. pulchra* in the coalfield is not strong, but the *Carbonicola* records indicate that this zone is probably present in the lower measures in the north-west and north-central portions of the field.

In the recently made collections now under consideration, however, lamellibranch evidence is not forthcoming for the presence of this zone. Concerning non-marine fossils other than lamellibranchs, three points of interest emerge.

Estheriella reumauxi Pruvost has been identified in the Tilmanstone Colliery No. 3 shaft-sinking, from levels varying between depths of 2819 ft. to 2970 ft. This radially ornamented species of Conchostracan crustacean has not previously been definitely recorded[2] outside the Pas de Calais Coalfield, where in the neighbourhood of Lens, it characterizes particularly the Dusouich Vein. It has been recorded from various levels in the Assise de Bruay, from the top of the Faisceau d'Ernestine to the Insect Bed in the Faisceau d'Edouard. These horizons range from the very top of the Zone of *A. phillipsi* to the Zone of *A. tenuis* of British usage.[3]

It might be noted that " the faint reticulation " of the surface of some of the specimens described by Bolton[4] as *Estheria tenella* (Jordan) from the shales over the High Vein of Coalpit Heath near Bristol, suggests that *Estheriella* may also occur in the Bristol Coalfield, though the figured specimens, lent through the kindness of Dr. F. S. Wallis of the Bristol Museum and Art Gallery, do not substantiate this.

Specimens of *Leaia* were collected from cores of the same Tilmanstone shaft-sinking taken, at 2902 ft. and 2970 ft. respectively. Those from the lower level definitely resemble the American species *L. tricarinata* Meek and Worthen. The typical form of this species has not yet been recorded from France or Belgium, though it is well known in Eastern N. America, also in South Wales where it occurs high in the Zone of *A. tenuis* (above the Mynyddislwyn Vein and its correlatives). It is also known in the Bristol Coalfield from the roof of the High Vein of Coalpit Heath Colliery and from the Kent Coalfield in cores from the Barfreston and Fredville borings.[5]

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[1] Wray, D. A., and A. E. Trueman, 'The Non-Marine Lamellibranchs of the Upper Carboniferous of Yorkshire and their zonal Sequence,' 'Summary of Progress' for 1930, Pt. iii (*Mem. Geol. Surv.*), 1931, Table A.

[2] Tchernychev, B., 'Sur *Estheria* et *Estheriella* du bassin de Donetz,' *Ann. Soc. Paléont. de Russie*, vol. vi for 1926, 1927, pl. vii, fig. 11, gives an unconvincing figure of a specimen named *E. reumauxi* Pruvost, from the coal horizon K_8^0 of the Donetz basin, but the figures of *Estheriella raricostata* Tchernychev (pl. vii, figs. 12-14) from the coal horizon " m_9 " appear to resemble Pruvost's species much more closely.

[3] Pruvost, P., 'La Faune continentale du Terrain houiller du Nord de la France,' *Mém. Carte Géol. France*, 1919, pp. 63-65, 550. Also Davies, J. H., and A. E. Trueman, 'A Revision of the Non-Marine Lamellibranchs of the Coal Measures and a Discussion of their zonal Sequence,' *Quart. Journ. Geol. Soc.*, vol. lxxxiii, 1927, p. 249. Prof. Pruvost considers *A. tenuis* to be synonymous with *A. phillipsi* and recognises only an undivided *A. phillipsi* Zone.

[4] 'Faunal Horizons of the Bristol Coalfield,' *Quart. Journ. Geol. Soc.*, vol. lxvii, 1911, pp. 324-5, pl. xxvii, figs. 1, 2.

[5] Pruvost, P., 'Découverte de *Leaia* dans le Terrain houiller du Nord et du Pas de Calais . . .', *Ann. Soc. Géol. du Nord*, vol. xliii for 1914, 1920, pp. 265-7. Bolton, H., *op. cit.*, 1915, p. 685.

It would appear from Mr. H. G. Dines' correlation of the Kent Coalfield borings that the Tilmanstone Leaias which occur somewhere near the junction between the Zone of *A. tenuis* and that of *A. phillipsi*, are stratigraphically lower than the Fredville and Barfreston occurrences.

The third non-marine record of interest is of the abdomen of the Arachnid, *Brachypyge carbonis* H. Woodward which was collected by Mr. W. Dewar from the roof of the No. 5 Seam at the Chislet Colliery. The type specimen of this species, which is also an abdomen similarly preserved (*i.e.* with the details of the dorsal and ventral surfaces pressed together) was described in 1878 from a colliery near Mons in the Zone de Wasmes of the Assise de Flénu of the Belgian Coalfield; it has, however, recently been restudied and refigured by Pruvost,[1] who has given new photographs differing fundamentally from the figure originally published by Woodward, and these enable close comparison to be made with the Kent specimen, which is preserved in counterpart [De. 4586, 4586A]. The present find constitutes the first record outside Belgium of this stratigraphically rather widely ranging Coal Measure species.

The Marine Fauna

The only marine fossils available for examination were from the borehole prolonging the Tilmanstone shaft-sinking and these were collected from cores at a depth of 3131 ft. and at frequent intervals between the depths of 3188 to 3210 ft. The list of identifications is appended. The rare goniatite remains were too fragmentary for identification, and of the shells, Productids and *Chonetes* were abundant though *Buxtonia* was rare.[2]

The marine fossils themselves at the present time afford little or no evidence enabling correlation to be made with other Coal Measure marine-horizons here or elsewhere in Europe, though it is hoped that the presence of Dr. T. N. George's recently described Reticulate Spiriferid genus,[3] *Phricodothyris sp.*, may have some bearing on future correlation work. It has not previously been recorded in British Coal Measure strata.

The highest marine horizons previously known in the British Coal Measures occur at the base of the Zone of *A. phillipsi* in S. Wales and the Midlands[4] and are noteworthy perhaps for their sharing the occurrence of species of *Myalina*, *Nuculana*, *Posidoniella* and *Pterinopecten*.

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[1] 'La Faune continentale du Terrain houiller de la Belgique,' *Mém. Mus. R. d'Hist. Nat. de Belgique*, No. 44, 1930, pl. xi, figs. 1, 1a, pp. 210-212.

[2] Bolton, H., 1915, *op. cit.*, p. 665, records *Buxtonia* [*Productus*] *scabriculus* as being the most common Productid in the marine Coal Measure material examined by him from Kent.

[3] George, T. N., 'The British Carboniferous Reticulate Spiriferidae,' *Quart. Journ. Geol. Soc.*, vol. lxxxviii, 1932, p. 524.

[4] Davies, D. Farr, E. Dix, and A. E. Trueman, 'Boreholes in the Cwm Gorse Valley,' *Proc. S. Wales Inst. Eng.*, vol. xliv, 1928, pp. 85-87.
Wilson, G. V., 'The Concealed Coalfield of Yorkshire and Nottinghamshire,' 2nd ed., (*Mem. Geol. Surv.*), 1926, p. 37.

Apart from *Nuculana* cf. *acuta* (J. de C. Sowerby) these genera have not been recorded from the Kent Coalfield; furthermore from Tilmanstone, cf. *Anthraconauta phillipsi* (Williamson) has been named by Dr. Trueman from a depth 214 ft. below the lowest observed marine fossil. This, with similar intervening lamellibranch-records, forces one to conclude that the Tilmanstone marine bands are probably stratigraphically higher than any yet observed in British coalfields, and lie within the Zone of *A. phillipsi*. In confirmation of this, one would note that *Anthraconauta tenuis* (Dix and Trueman) has been identified from a depth of 2783 ft., *i.e.* only 348 ft. above the highest marine occurrence; similarly *A.* aff. *tenuis* was recorded from a depth of approximately 2920 ft.

From Mr. H. G. Dines' correlations of the Kent borings[1] which are based on coal seams and other lithological considerations only, it would appear that all the undoubted Kent Coal Measure marine horizons occupy the same general stratigraphical horizon. With the limited specimens and records at one's disposal, it is not possible seriously to combat this conclusion on palaeontological grounds, in fact there is much to support it.

Dr. Bolton (*op. cit.*, 1915) recorded undoubted marine strata from five borings, namely Walmestone, Mattice Hill, Barfreston (where there are two marine horizons 260 ft. apart), Ripple and Oxney. At Barfreston the lower of the two marine horizons is that most closely correlated with the Tilmanstone marine strata by Mr. Dines from lithological considerations. Below the marine strata studied by him, from Walmestone, Mattice Hill, the higher horizon at Barfreston, and from Ripple, Dr. Bolton recorded *Anthracomya phillipsi*, so that if the identification is correct these strata should fall also within the Zone of *A. phillipsi*. From a depth of 3111 ft. at Oxney, *i.e.* from about 200 ft. below the marine band, Dr. Bolton figured a lamellibranch which he named *Sanguinolites sp.* (*op. cit.*, 1915, pl. ix, fig. 16). This specimen, through the kindness of Dr. F. S. Wallis of Bristol, I have been allowed to examine and submit also to Professor Trueman; it is a poorly preserved specimen of *Anthracomya*, possibly allied to *Anthracomya pringlei* Dix and Trueman, but one cannot place much weight on this occurrence.

Dr. Bolton did not publish a correlation of the Kent marine horizons among themselves, but he considered that they all fell into the "Lower Series of Coal Measures." The rich fauna from a depth of 2891 ft. at the Oxney boring he concluded to be "somewhat reminiscent of the [marine fauna of the] Vobster, Ashton and Bedminster Series of the Bristol and Somerset coalfields and typically of Lower Coal-Measure age."[2]

That any Lower Coal Measure strata are present in the Kent Coalfield has already been doubted by Wheelton Hind, Arber, Pringle and Crookall[3] and others, but it does not appear that previous

[1] Dines, H. G., 'The Sequence and Structure of the Kent Coalfield,' 'Summary of Progress' for 1932, Pt. ii (*Mem. Geol. Surv.*), 1933, p. 27, pls. III, IV.
[2] *Op. cit.*, 1915, p. 668.
[3] Pringle, J., and R. Crookall, 'On Fossils from the Coal Measures of Kent,' 'Summary of Progress' for 1927, Pt. ii (*Mem. Geol. Surv.*), 1928, p. 85.

publication has been given to the opinion that the Kent Coal Measure marine strata are definitely of a different geological horizon from those near Bristol.

In 1907, Dr. Bolton[1] described a marine band occurring in the Ashton Vale Colliery, 84 ft. below Gay's Vein, *i.e.* 286 ft. below the Ashton Great Vein, which contained goniatites listed by him as *Glyphioceras carbonarium* (von Buch), *Gastrioceras coronatum* Foord and Crick, *G. listeri* (Martin) and of these, the first named was stated to be the most abundant. Semper[2] later listed this *G. carbonarium* in the synonymy of "*Glyphioceras subcrenatum* Schlotheim." I have not been able to examine these specimens but judging from Bolton's description it seems likely that he was dealing with *Gastrioceras subcrenatum* (Schlotheim MS.) C. Schmidt, and the association with *G. listeri* is quite a possible one. Of the other Bristol Coal Measure marine band described by Dr. Bolton in 1911[3] from South Liberty Hall Colliery, from strata in the neighbourhood of the Toad Vein, goniatite specimens presented by Dr. Bolton to the Geological Survey (and numbered Z. 124, Z. 128 and Z. 4794) have been examined, also certain specimens in the Bristol Museum and Art Gallery. This material contains undoubted *Gastrioceras subcrenatum*, so it would appear that these two Bristol marine bands, whether they are distinct or whether they are of similar horizon, are truly of Lower Coal Measure age, accepting the Yorkshire position of the *G. subcrenatum* Zone as a standard; and there, this zone falls within the non-marine lamellibranch Zone of *Anthracomya lenisulcata*. This being so, it is in the highest degree improbable that the marine strata which occur at Tilmanstone in the Zone of *A. phillipsi* are contemporaneous with the marine strata examined from those two collieries of the Bristol Coalfield. From the available evidence it also seems likely that, after the Kent Carboniferous Limestone surface was elevated and any later deposits were denuded, a subsidence occurred in *A. pulchra* Zone times when the *Anthracoceras aegiranum*[4] sea invaded parts of N. Europe. In Kent, this depression left swamp- and not marine-deposits until the sea temporarily entered at a period but slightly later than that in which the Cwm Gorse marine strata were deposited in South Wales.

Faunal List

The following names apply to specimens collected from the Coal Measure strata of Kent by Messrs. A. Templeman and W. Dewar during 1930. The specimens are identifiable by the numbers in square brackets as registered in the MS. books of the Boring and

[1] Bolton, H., 'On a Marine Fauna in the Basement Beds of the Bristol Coalfield,' *Quart. Journ. Geol. Soc.*, vol. lxiii, 1907, pp. 447-449, 466.

[2] Semper, M., 'Die mariner Schichten im Aachener Obercarbon,' *Verh. Naturhist. Ver. Preuss. Rheinl.*, Bd. lxv für 1908, Bonn, 1909, p. 260.

[3] Bolton, H., 'Faunal Horizons in the Bristol Coalfield,' *Quart. Journ. Geol. Soc.*, vol. lxvii, 1911, p. 319.

[4] Bisat, W. S., 'On the Goniatite and Nautiloid Fauna of the Middle Coal Measures of England and Wales,' 'Summary of Progress' for 1929, Pt. iii (*Mem. Geol. Surv.*), 1930, Table A, facing p. 76.

Palaeontological Departments respectively. The non-marine lamellibranchs were named by Professor A. E. Trueman and the other fossils by Dr. C. J. Stubblefield.

Betteshanger Colliery, ¾ mile N.N.E. of the church, Northbourne.

Roof of F Seam:—*Spirorbis sp.*, *Anthracomya pringlei* Dix and Trueman, *A.* cf. *pringlei*, *Anthracomya spp.* [including two new species, '*sp. nov.* 3' and '*sp. nov.* 5.' A.E.T.], *Anthraconauta* [*Anthracomya*] *phillipsi* (Williamson), *A.* (*A.*) cf. *phillipsi*, *A.* (*A.*) cf. *tenuis* (J. H. Davies & Trueman), *Euestheria sp.* [De. 714-760].

Roof of I Seam:—*Anthraconauta* cf. *phillipsi* (Williamson) also a rather naiaditi-form shell with a long anterior end, A.E.T. [De. 761-763].

Chislet Colliery, 1¾ miles S.S.W. of Chislet.

Roof of No. 5 Seam:—*Brachypyge carbonis* H. Woodward [De. 4586-4586A].

Snowdown Colliery, 2⅛ miles N.N.W. of Shepherdswell.

Roof of Snowdown Seam:—*Anthracomya* cf. *pringlei*, Cf. *A. pringlei*, *A.* cf. *pruvosti* Tchernychev, *Anthracomya sp.*, *Anthraconauta* cf. *phillipsi*, also a rotund form of *A.* cf. *phillipsi* [De. 764-781].

Tilmanstone Colliery: No. 3 shaft-sinking, 1⅛ miles S.W. of Tilmanstone.

Depth	
2756-2761 ft.	*Anthraconauta* cf. *phillipsi* (Williamson), *A.* aff. *phillipsi*, *A.* aff. *tenuis* (Davies & Trueman) [with a wider angle α than the type], Cf. *A. tenuis* [Ba. 2822-2826].
2783 ft.	*A. phillipsi*, *A.* cf. *phillipsi*, *A. tenuis*, *Anthraconauta sp.* [juv.] [Ba. 2827-2832].
2790-94 ft.	*A. phillipsi*, *A.* aff. *phillipsi* [rotund form as De. 765], *A.* cf. *tenuis*, *Anthraconauta sp.*, Fish scale [Ba. 2833-2840].
2819-2834 ft.	*Anthracomya pringlei* Dix & Trueman, *A.* cf. *pringlei*, Cf. *A. pringlei*, *A. pruvosti* Tchernychev [= *A. wardi* Pruvost *non* R. Etheridge sen.] *Anthracomya spp.* [including three new species, '*sp. nov.* 1,' '*sp. nov.* 2' and '*sp. nov.* 3'] *Anthraconauta* cf. *phillipsi*, *Estheriella reumauxi* Pruvost [Ba. 2841-2864].
2834-2835 ft.	*Anthracomya pringlei* [typical], Cf. *A. pringlei*, *Anthracomya sp.*, *E. reumauxi*, *Euproops sp.*, Palaeodictyopterid or Blattoid wing[1] [Ba. 2865-2879].
2902 ft.	*Anthraconauta* cf. *phillipsi*, *Euesteria*?, *Leaia sp.* [Ba. 2881-6].
2916-2924 ft.	*Spirorbis sp.*, *Anthracomya* aff. *pringlei*, *Anthraconauta* cf. *phillipsi* [including forms tending towards *A. tenuis*], *A.* aff. *phillipsi*, *A.* aff. *tenuis*, Cf. *Estheriella reumauxi*, *Euestheria sp.*, Ostracods [Ba. 2887-2899].
2966 ft.	*Estheriella reumauxi* Pruvost, Cf. *E. reumauxi* [Ba. 2900-02].
2966-2970 ft.	*Anthracomya pringlei*, *A.* cf. *pringlei*, *A.* aff. *pringlei*, *A. pruvosti*, *Anthraconauta phillipsi* ?, *A.* cf. *phillipsi*, Cf. *A. phillipsi*, *Anthraconauta sp.*, *Estheria sp.*, *Estheriella reumauxi* [Ba. 2912-2938].
2970 ft.	*A.* cf. *phillipsi*, *Estheria sp.*, Cf. *Estheriella reumauxi*, *Euestheria simoni* Pruvost, Cf. *E. simoni*, *Leaia tricarinata* ? Meek & Worthen, *Euproops sp.* [Ba. 2903-2911].
2975 ft.	*Anthraconauta* cf. *phillipsi* [Ba. 2939].

[1] This insect wing was named by Dr. H. Bolton.

Borehole from shaft-sinking.

3131 ft.	*Buxtonia* ?, *Lingula mytiloides* J. Sowerby, *Productus sp.*, *Productus* (*Dictyoclostus* ?) *sp.*, *Protoschizodus* ?, *Orthoceras sp.*, *Anthracoceras* ? [Ba. 3372-78].
3188 ft.	Crinoid stem columnals, Cf. *Prothyris sp.*, Cf. *Hyolithus* ? *sturi* Klebelsberg, *Temnocheilus*?, Ostracod indet. [Ba. 3385-86].
3189 ft.	*Chonetes sp.*, *L. mytiloides*, *Orbiculoidea* cf. *nitida*(Phillips), *Phricodothyris* ?, '*Bellerophon*' *sp.* [Ba. 3387-89].
3190 ft.	*Enchostoma sp.*, Cf. *Chonetes laguessiana*, mut. θ Hind; *Chonetes sp.*, *Martinia*?, *Phricodothyris sp.*, *Productus* (*Eomarginifera*) *sp.*, Cf. *Productus* (*Linoproductus*) *tortilus* M'Coy, *Aviculopecten* ?, *Orthoceras sp.* [no ornament visible], Cf. *Jonesina* [*Beyrichia*] *arcuata* (Bean) [Ba. 3390-96].
3191 ft.	Crinoid stem, Cf. *Chonetes laguessiana*, mut. θ, *Orthotetes* ?, *Phricodothyris* ?, *Productus* (*Dictyoclostus*) *sp.*, *P.* (*Eomarginifera*) cf. *longispinus* J. Sowerby, Cf. *P.* (*Linoproductus*) *tortilus* M'Coy, Cf. *J. arcuata* [Ba. 3397-3401].
3192 ft.	Crinoid stem columnal, *Chonetes laguessiana*, mut θ, *Orbiculoidea* cf. *nitida*, *Phricodothyris sp.*, *Productus* cf. *carbonarius* de Koninck, *P.* (*D.*) cf. *semireticulatus* (Martin), *P.* (*Dictyoclostus*) *sp.*, *P.* (*E.*)cf. *longispinus* [Ba. 3402-3412].
3193-3197 ft.	Crinoid stems, *C. laguessiana*, mut. θ, *Chonetes sp.*, *Lingula mytiloides*, *Orbiculoidea* cf. *nitida*, *Orthotetes* ?, *Phricodothyris*?, *Productus* cf. *carbonarius*, *P.* (*E.*) cf. *longispinus*, *P.* (*Linoproductus* ?) *sp.*, *Orthoceras* cf. *asciculare* Brown [Ba. 3413-21].
3198-3200 ft.	*C. laguessiana*, mut. θ, *Chonetes sp.*, *Orbiculoidea* cf. *nitida*, *Phricodothyris sp.*, *Productus* (*Dictyoclostus*) *sp.*, *P.* (*Eomarginifera*) *sp.* [Ba. 3422-3424].
3202 ft.	*L. mytiloides*, *O.* cf. *nitida*, *Aviculopecten* ?, *Ctenodonta* cf. *laevirostris* (Portlock), *Nucula* cf. *gibbosa* Fleming, *Nuculana* cf. *acuta* (J. de C. Sowerby), *Pseudamusium* ?, *Loxonema*, *Orthoceras* cf. *asciculare* [Ba. 3425-30].
3204-3209 ft.	*L. mytiloides*, *O.* cf. *nitida*, *Productus* ?, *C.* cf. *laevirostris* '*Loxonema*' *sp.* [small, no visible ornament], Goniatite 'fry', Fish scale [Ba. 3431-38].
3210 ft.	*Buxtonia sp.*, *L. mytiloides*, *O.* cf. *nitida* [Ba. 3439-41].
3214 ft.	Indeterminate Fish scale [Ba. 3442].
3406 ft.	*Anthracomya sp.* [Cf. *Anthracomya sp. nov.* J. H. Davies & Trueman, *Quart. Journ. Geol. Soc.*, vol. lxxxiii, 1927, pl. xvii, fig. 8, not exactly the same shell but probably a related form. A.E.T.] [Ba. 3472A].
3413 ft.	? *Anthraconauta phillipsi* (Williamson) [Ba. 3474].
3414 ft.	*Anthracomya sp.* [? near *A. pruvosti* Tchernychev] [Ba. 3475].
3448 ft.	Cf. *A. phillipsi* (Williamson) [Ba. 3480].

NOTE.—Between the depths of 3188 ft. and 3210 ft. marine fossils were collected by Mr. Templeman from practically every foot of core ; for the purposes of this list some of the records have been placed together over a range of depths.

III.—THE GAULT OF CAMBRIDGESHIRE

BY

E. E. L. Dixon, B.Sc., A.R.C.Sc.

THE Gault of Cambridgeshire is of interest because it is situated between the type development, which is found in the Home Counties, and the attenuated calcareous facies present in West Norfolk, which reaches its extreme development in the 'Red Chalk' of Hunstanton. It is, however, poorly exposed and what is seen is largely unfossiliferous.

In accordance with the view that the phosphates of the overlying Cambridge Greensand were derived largely from Upper Gault horizons but in part even from Lower Gault, it was for many years thought that the Upper Gault was nowhere present in the county. In 1904 Prof. Fearnsides showed[1] that the Gault at Barnwell near Cambridge, to a depth of at least 42 ft. (below the junction with the Cambridge Greensand), belongs to the Upper subdivision, and concluded further that this was not merely a local relic. Nevertheless, in the absence of additional evidence, the general view appears to have been that the Barnwell Gault is local. The chief reason for this opinion has already been controverted by Dr. L. F. Spath,[2] who has shown that the supposed abundance of Lower Gault fossils in the Cambridge Greensand is based on faulty identifications and that the fauna is uppermost Albian (Upper Gault).

As the exposures at Barnwell and Barrington described by Fearnsides, like most gault pits in the county, are overgrown, it is fortunate that a well and boring at Wicken, 10 miles north-east of Cambridge, facilities for examining which we owe to the engineers, Messrs. G. W. Lack and Sons, and their manager, Mr. E. R. Claydon, have passed through a fossil-bed with a typical Upper Gault fauna and, in addition, have revealed its distance above the local Lower Greensand. Ammonites, many keeled and some of them half a foot or so in diameter, are abundant, and lamellibranchs, though of few genera, are also numerous, especially the characteristic Upper Gault form, *Inoceramus sulcatus* Parkinson. True gastropods are absent, the other macroscopic fossils being chiefly small belemnites and species of *Dentalium*, *Terebratula* and *Isocrinus*, with a few small corals. No evidence of condensation or retarded deposition was noticed in the fossil-bed. Some of the fossils were filled with soft, pale brown phosphate, but no hard black phosphates were seen in this bed.

The facies of the ammonites, and the dominance and large size of *I. sulcatus*, prove that the bed is of Upper Gault age, or

[1] 'Occurrence of a Limestone with Upper Gault Fossils at Barnwell, near Cambridge,' *Quart. Journ. Geol. Soc.*, vol. lx, pp. 360-363.

[2] 'Ammonite Horizons of the Gault and contiguous Deposits,' 'Summary of Progress' or 1922 (*Mem. Geol. Surv.*), 1923, App. II, pp. 142-143.

more precisely, Dr. Kitchin suggests, that it includes the horizon of the top part of Price's Bed IX of the Folkestone Gault, the Orbignyi Zone of Dr. Spath's classification.[1] From an examination of the ammonites Dr. Spath concludes that the overlying Varicosum Zone (Bed X) also has some representation. The abundance of the *Inoceramus* distinguishes the Wicken fossil-bed from that at Barnwell; the latter, though correlated at first with Bed IX, "is now considered to correspond more closely to Bed X and the lower part of Bed XI."[2]

The position of the Wicken bed in the Gault appears from the following details:—

	Sunk Well and Boring at Chapel Lane, Wicken	Ft.
9.	Soil	1
4-8.	GAULT:—	
8.	Clay, calcareous and almost white when dry	18
7.	Fossil-bed, in clay somewhat less pale than that above, part with small dark spots	5
6.	Clay like 7 but with few fossils	2
	[The beds below were bored]	
5.	Clay with occasional small belemnites and, a foot above the base, a dark hard phosphatic cast of *Inoceramus concentricus* Parkinson	29
4.	Sandy clay, blue, with streaks of brown sand; a few rough fragments of sandstone and occasional small smooth quartz-pebbles and worn chips of chert, etc.	5
2-3.	LOWER GREENSAND:—	
3.	Sandstone and sand, ferruginous and with scattered glauconite; cemented hard at the top, variable below; frequent small pebbles and chips like those in 4 and occasional yellow-brown phosphates	2½
2.	Sandstone, dark grey, hard, pyritous and glauconitic ...	0½
1.	JURASSIC, probably Ampthill Clay:—dark clay with a hard pyritous bed	5
		68

The fossil-bed lies, then, 36 ft. above the base of the Gault. The full thickness hereabouts of the Gault, according to information from Messrs. G. W. Lack and Sons, is about 110 ft., of which, therefore, at least 74 ft. belongs to the Upper Gault.

From other evidence it would appear, indeed, that close to Wicken either the whole thickness is Upper Gault, or that it includes, at most, some representation of the topmost zone of the Lower Gault. Some of the lowest layers of the Gault at Upware, which is 2 miles west of the Wicken well, contain abundant *Inoceramus sulcatus* and ammonites that have been recorded as '*Ammonites interruptus*.'[3] This implies an incompatible association, since the true '*A. interruptus*,' that is to say *Hoplites dentatus* (J. Sowerby), characterizes the lowest zone of the Gault Clay

[1] In 'Handbook of the Geology of Great Britain,' 1929, p. 393.
[2] 'The Geology of the Country near Saffron Walden' (*Mem. Geol. Surv.*), 1932, p. 10.
[3] Fearnsides, W. G., in 'Natural History of Cambridgeshire,' 1904, p. 25.

present at Folkestone, whereas the *Inoceramus* is confined to Beds VIII and IX of the Folkestone Gault, and equivalent horizons elsewhere, the larger specimens occurring abundantly at the top of Bed IX. This latter species is an unmistakable fossil, and the record of its occurrence at Upware is of much more value than that of '*Ammonites interruptus*.' Dr. Spath has pointed out[1] that Hoplitids of higher horizons have often been wrongly identified as *H.* '*interruptus*.'

The palaeontological evidence that the Gault at Upware almost from the base upward belongs to the Upper subdivision is confirmed by the fact[2] that at that place the Gault Clay rests on the Lower Greensand immediately and unconformably, for Messrs. Kitchin and Pringle,[3] in confirmation of the work of Professor Barrois, have found that, where the sandy Mammillatus Bed is absent and Gault Clay rests upon the Lower Greensand directly, the clay belongs to the Upper subdivision.

It may be remarked parenthetically that if the movement of transgression took place, as those authors have suggested, at about the time of the deposition of the Cristatum Zone, the uppermost member of the Lower Gault, there may possibly be some representation of that zone at the base of the transgressive strata. The term 'Upper' subdivision should therefore be understood, in this connection, to be applied with this reservation.

At Upware the Mammillatus Bed is absent, and the few feet of Lower Greensand is known, from the abundant fossils obtained in the past from coprolite-workings, to be of the age of the Hythe Rag (mid-Aptian).[4] The upper zones of the Aptian, therefore, are missing, as well as the Lower Albian (the greater part of which is quite unrepresented in this country) and the Middle Albian (Lower Gault). The records of '*Ammonites interruptus*' are either faulty or, as some at least refer to specimens from a basal phosphate-bed, possibly indicate the presence of material derived from the Lower Gault.

The question, therefore, arises, whether any Lower Gault, apart from the topmost bed (perhaps represented there), is likely to be present at Wicken, where the Lower Greensand is as attenuated and of the same age as that at Upware.

In their paper Messrs. Kitchin and Pringle show[5] that in parts of Bedfordshire to the south-west the Gault consists chiefly of the Upper subdivision, which in places transgresses the Lower Gault and rests unconformably on Lower Greensand. At West Dereham in Norfolk, too, where the Gault emerges from beneath the Fens north of Wicken, they find that the Lower Gault, though again present,

[1] *Op. cit.*, 1923, pp. 139, 140.
[2] Bonney, T. G., 'Cambridgeshire Geology,' 1875, pp. 64-66.
[3] 'On the Overlap of the Upper Gault in England and on the "Red Chalk" of the Eastern Counties,' *Geol. Mag.*, 1922, p. 158. The Mammillatus Bed has in the past been referred by some to the Gault, by others to the Lower Greensand. It is the basal member of the Lower Gault (Middle Albian), and much later in time than the highest beds of the true Lower Greensand (Aptian) in this country. For the zones of the Aptian and Albian see Dr. Spath's tables reproduced in the 'Handbook of the Geology of Great Britain,' 1929, pp. 385, 393.
[4] Spath, L. F., *op. cit.*, 1923, p. 148.
[5] *Op. cit.*, pp. 164-166.

only gives representation of the Zone of *Hoplites dentatus* (= *H. interruptus*) and of that of *Douvilleiceras mammillatum* below.[1] They regard this Lower Gault as merely a thin remnant spared by the erosion that preceded the deposition of the Upper Gault.[2] In other borings in south-west Norfolk described by Dr. Pringle,[3] not a remnant of the Lower Gault has been left. At Methwold Common and Severals House, south-east of West Dereham, the transgressive Upper Gault rests upon thin relics of the lowest part of the Lower Greensand (Sandringham Sands). The almost complete removal here of the Lower Greensand must be regarded as due to the recurrent denudation of which we have evidence in the pre-*mammillatum* discordance and in the later transgression at the close of Lower Gault time.

We conclude, then, that at Wicken, as at Upware, at Methwold and in parts of Bedfordshire, the Gault may belong wholly to the Upper subdivision (with the above-mentioned reservation),[4] resting unconformably on Lower Greensand.

As to the Gault through the rest of Cambridgeshire between Wicken and Bedfordshire, with the exception of that near Cambridge, we know little beyond the change in thickness, which has been proved in borings for water into the Lower Greensand below. From Wicken the thickness increases south-westward to 180-200 ft. near Bedfordshire, with sufficient regularity to show that the constitution of the Gault undergoes no such vital change as, for instance, a virtual disappearance of the chief member, the Upper Gault. Throughout Cambridgeshire, therefore, the greater part of the Gault appears to be Upper, with the Lower possibly absent in places. Indeed, the only instance of the occurrence of a Lower Gault ammonite in Cambridgeshire hitherto published in the course of the revision[5] of available material by Dr. Spath is that of *Hoplites dentatus* from Oakington, a place close to the outcrop of the base of the Gault. So far from the general existence of the Upper Gault in this county being in question, the boot is on the other foot! Whether, or to what extent, the south-westward thickening is due to an incoming of Lower Gault is unknown.

Some irregularity is observable in the thickening. Thus, in some recent borings[6] the Gault thins from 162-179 ft. at Barrington to 117-125 ft. near Orwell, a westward decrease of 50 ft. in 2½ miles. Although the irregularities may be due to the known unevenness of the top of the Gault, other evidence from borings points definitely to a physical break[7] at the base. The available cores from these latter borings show that the base succeeds the Lower Greensand more or

[1] These zonal determinations have since been confirmed by Dr. Spath.

[2] See also F. L. Kitchin, and J. Pringle, 'The Stratigraphical Relations of the Red Rock at Hunstanton,' *Geol. Mag.*, 1932, p. 33.

[3] Pringle, J., 'On the Concealed Mesozoic Rocks in South-West Norfolk,' 'Summary of Progress' for 1922 (*Mem. Geol. Surv.*), 1923, App. I, pp. 126-139.

[4] This reservation is made by Dr. Kitchin. Dr. Spath also doubts whether the 36 ft. or so of Gault below the Wicken fossil-bed is entirely Upper Gault.

[5] 'A Monograph of the Ammonoidea of the Gault' (*Palaeontographical Society*), 1923—.

[6] By Messrs. C. Isler and Co. and Messrs. G. W. Lack and Sons.

[7] In addition to the palaeontological break, which may be presumed to exist from the absence in this country of the greater part of the Lower Albian.

less abruptly and, although for a thickness of as much as 10 ft. or so it encloses an abundance of sand and small cherts and other stones together with ferruginous ooliths, the whole like those in the Greensand below, it includes also fragments (rough or well-rounded pebbles) of glauconitic and iron-shot sandstones, which are undoubtedly rolled debris of the Greensand.

This sandy basement-bed encloses a few phosphates, some at least with included sand-grains, and in places it is followed by a thin phosphate-bed before the pure Gault Clay sets in. The sandy phosphates suggest the presence of the Mammillatus Bed but have yielded no palaeontological evidence. The question of stratigraphical relationship is not affected thereby; at West Dereham the junction of the Mammillatus Bed with the Lower Greensand is uneven.[1]

It is to be hoped that further evidence will be forthcoming from other borings and excavations, but material for the complete story of the variation in the constitution of the base of the Gault from place to place in Cambridgeshire will presumably never be available.

In the study of the top of the Gault matters have been very different, thanks to the coprolite-workings in the overlying Cambridge Greensand, which have bared the junction practically from end to end of the county. These have shown that prior to the deposition of the Greensand the Gault Clay was channelled and eroded both on the small scale that is apparent in exposures and also on a larger amplitude. At the same time the abundant collections of Cambridge Greensand ammonites have enabled Dr. Spath[2] to show that this deposit is a condensed representative of the highest Albian (Gault or Upper Greensand) zones of certain places elsewhere.

Although the erosion of the Gault Clay is possibly due to current-action only, its comparatively widespread character suggests emergence and some degree of subaërial erosion. In either case a local uplift, followed by renewed subsidence, is apparent. The uplift, as Dr. Rastall has shown,[3] may well have been related to the Charnian axis that passes through Charnwood Forest. The subsidence, like those of earlier Gault times, was part of the great movement that brought about the Cenomanian transgression.

The writer is indebted to Drs. Kitchin and Spath for determining the zonal position of the Wicken fossil-bed, and to the former for much helpful discussion and suggestion.

[1] Jukes-Browne, A. J., 'The Gault and Upper Greensand of England' (*Mem. Geol. Surv.*), 1900, p. 298.

[2] 'Ammonite Horizons of the Gault and contiguous Deposits,' *op. cit.*, 1923, pp. 142-143. The relations of the ammonites of the Cambridge Greensand are discussed by him in detail in 'Ammonoidea of the Gault,' *op. cit.*

[3] 'Geology in the Field,' 1909, pp. 140-156; 'Tectonics of the Southern Midlands,' *Geol. Mag.*, 1925, pp. 193-222.

IV.—COMPOSITE AUTO-INTRUSION IN A CARBONIFEROUS LAVA FLOW

BY

W. Q. KENNEDY, D.Sc.

Plate VIII.

INTRODUCTION

THE problem of composite igneous bodies, both intrusive and extrusive, has an important bearing on certain of the major problems of petrogenesis. It will be admitted by all petrologists that a solution of the origin and mode of emplacement of the basalt-granophyre composite minor intrusions will go far towards solving the vexed question of the basic to acid order of intrusion in plutonic masses. For this reason any additional data must be carefully considered.

In a former paper the author[1] drew attention to the presence, in Renfrewshire and the Isle of Skye, of certain unique lava flows within which two rock-types were associated in an intimate and regular manner. Further work has proved the rather widespread nature of such composite lavas within the Renfrewshire area while, at the same time, a new type has been recognised which differs from the former known occurrences both in structure and composition. In addition, this new variety of composite flow shows most interesting internal hybridization which, from the nature of the rocks concerned, was not apparent in the earlier described examples.

FIELD RELATIONS

The Lower Carboniferous (Calciferous Sandstone Series) volcanics of Renfrewshire and North Ayrshire have been divided by Richey[2] into a Lower Group of felspathic basalts and mugearites and an Upper Group of olivine-rich basalts with trachytes and trachyandesites.

The composite flow under consideration occupies a horizon about the middle of the Lower Group and forms one of the few known occurrences of trachyandesite within the felspathic basalt series. The lava outcrops in Craigmarloch Wood, about one and a half miles north-west of Kilmacolm village, where it forms an outlier. It is encountered again on the rough moorland south of the River Gryffe some one and a half miles to the south-east of the former outcrop.

[1] Kennedy, W. Q., 'On Composite Lava Flows,' *Geol. Mag.*, vol. lxviii, 1931, pp. 166-181.
[2] Richey, J. E., *Trans. Geol. Soc. Glasgow*, vol. xvii, 1927-28, pp. 247-258; J. E. Richey and others in 'The Geology of North Ayrshire' (*Mem. Geol. Surv.*), 1930, p. 69.

In spite of the detached and widely separated nature of the two outcrops there is no doubt that they belong to a single, originally continuous body as they occupy equivalent positions in the volcanic sequence. This is apparent when the succession in the two localities is compared.

South of Gryffe Valley	*Craigmarloch Wood*
(e) mugearite	—
(d) felspar-phyric basalt	—
(c) *composite flow*	(c) *composite flow*
(b) felspar-augite-phyric basalt	(b) felspar-augite-phyric basalt
(a) mugearite	(a) mugearite

The felspar-augite-phyric basalt (b in the sequence) is a highly distinctive type, uncommon in the district, and its occurrence immediately below the composite lava in both localities cannot be fortuitous. In addition, the thick mugearite (a in the sequence) can be traced continuously across the valley floor and its position with regard to the higher lavas is definitely established.

The composite flow itself is marked by the intimate, mutual association of two distinct and contrasted rock-types, the first a dark coloured, exceedingly fine-grained mugearite free from phenocrysts, and the second a more coarse-grained, pale trachyandesite with many small phenocrysts of flesh-coloured felspar, black augite and pseudomorphs after olivine.

The trachyandesite forms a central portion flanked above and below by mugearite against which the contact is very indefinite. Locally either the upper or lower mugearite, but never both, may be absent and, as a whole, the thicknesses of the three members are rather variable. The lower mugearite is always thin and rarely exceeds twelve feet. The trachyandesite varies from about twelve to twenty-five feet, while the upper mugearite has an average thickness of approximately twenty feet.

The Kilmacolm composite flow shows, in general, a marked bilateral symmetry, a feature in which it resembles the basalt-granophyre minor intrusions of the Hebrides[1] and in which it differs from the previously described composite flows.[2]

External Contacts.—Careful examination of the external (upper and lower) contacts leaves no doubt as to the effusive nature of the flow as a whole. In the Craigmarloch Wood outcrop only the base of the lava is visible, the overlying volcanics having been removed by erosion. The base, however, shows all the characteristics of an effusive sheet and consists of a slaggy, vesicular, brecciated layer which passes gradually upwards into the massive rock of the flow. On the northern margin the central trachyandesite appears

[1] Harker, A., 'The Tertiary Igneous Rocks of Skye' (*Mem. Geol. Surv.*), 1904, pp. 197-234. E. B. Bailey and H. H. Thomas in 'The Tertiary and Post-Tertiary Geology of Mull' (*Mem. Geol. Surv.*), 1924, p. 32. G. W. Tyrrell, 'The Geology of Arran' (*Mem. Geol. Surv.*), 1928, p. 123. J. E. Richey and H. H. Thomas, 'The Geology of Ardnamurchan' (*Mem. Geol. Surv.*), 1930, p. 62.

[2] Kennedy, W. Q., *op. cit.*, 1931, p. 178.

to have broken through the basal mugearite and it comes to rest with a slaggy, vesicular base on the underlying lava.

The top of the composite flow, as seen to the south of the Gryffe valley, is highly vesicular and slaggy. It can be traced downwards into the massive interior. On the extreme west, the upper mugearite disappears entirely and the overlying felspar-phyric basalt (d of the sequence) rests directly on vesicular trachyandesite for a short distance. Owing to the curious nature of the Kilmacolm flow considerable care was taken with the establishment of its effusive nature and the observations were checked in the field by my colleagues Messrs. J. E. Richey and A. G. MacGregor who subscribe to the extrusive nature of the occurrence.

Internal Contacts.—The internal contact phenomena, most clearly seen in the Craigmarloch Wood outlier, closely recall the relations found in the basalt-granophyre composite sills and dykes of the Hebrides.

There is complete absence of chilling at the contact of the central trachyandesite with the upper and lower mugearites. The passage from the acid centre to the basic margins is gradual and takes the form of an upper and lower transition zone, several feet in thickness, within which an intimate mixture of the two rock-types has occurred. The trachyandesite from the transition zones is modified in composition and crowded with rounded, strongly resorbed xenoliths, patches and schlieren of mugearitic material. In the neighbourhood of the internal contacts the platy structure of the mugearite is highly contorted and the basic rock is riddled with veins of trachyandesite. This network of veins extends for several feet into the massive mugearite and attests to the extreme fluidity of the trachyandesite magma, an unusual character in a magma of such composition.

From the nature of the internal contacts and the manner in which the acid magma has permeated the basic rock it is evident that the latter must have been extremely hot and, to some extent, still liquid when the trachyandesite became emplaced. The two magmas must have followed each other in rapid succession and without any appreciable time interval. The field evidence points, moreover, to the fact that the formation of the composite flow took place prior to the extrusion of the overlying felspar-phyric basalt and that both the associated rock-types consolidated under truly effusive conditions. This is borne out by the vesicular nature of the trachyandesite top where it has broken through the enclosing mugearite. Further, the acid rock occupies the central portion of a massive flow and, if a later intrusion, it is highly improbable that it would have chosen the massive centre of the flow in preference to the easier path along the base or top. The internal contacts are, moreover, unlike anything found in a minor intrusion with the exception of those of composite nature. Finally, although the trachyandesite locally comes into contact with the overlying felspar-phyric basalt it is nowhere found to alter or vein the latter.

Mode of Formation

The intimate association of the two distinct rock-types which characterises the Kilmacolm flow depends on two established facts of igneous geology, (1) the phenomenon of *auto-intrusion* and (2) the sudden change in composition of the magma being erupted or intruded.

During the flow of lava on the surface, two main conditions are recognised :—

(1) The cooling and friction along the base of the flow leads to retardation of the lower layers with relative acceleration of the upper part. By means of this differential flow, the later extruded lava tends to be transferred towards the front of the flow as a fast moving upper layer.

(2) Cooling and consolidation may proceed simultaneously at the top and bottom while liquid magma continues to circulate within the interior. In modern flows this condition is proved by the occurrence of '*hornitos*.' Movement within the interior may, therefore, result in '*auto-intrusion*' of the fluid central portion into its already solidified crust.

This latter effect was postulated by Bailey[1] to explain the internal relations of the Sgùrr of Eigg pitchstone and, subsequently, the widespread nature of the phenomenon was recognised by officers of the Geological Survey among the lava fields of the Hebrides.[2]

In Eigg, the lava consolidated as a pitchstone which is veined by and merges into a porphyry representing the final consolidation of the central portion. The two rocks differ in structure but are identical in their chemical composition.[3]

In the case of the Kilmacolm lava the associated rocks differ considerably in composition (there is a difference of about 15 per cent. silica) although their mutual relations resemble those of the Sgùrr of Eigg. Further the two magmas must have existed as such before extrusion. The origin of the bilaterally symmetrical nature must depend, therefore, on composite extrusion combined with auto-intrusion.

The process started with extrusion of the mugearite which commenced to cool and solidify from the top and base leaving a liquid central portion in which magma was still circulating. At some point during extrusion the mugearite magma suddenly gave place to trachyandesite which followed the liquid path along the centre of the flow, swept on the basic lava and came to occupy its position. The process is exactly analogous to that which gave rise to the composite basalt-granophyre sills and dykes of the Tertiary province. Locally the acid magma broke through and destroyed the enclosing mugearites much in the same manner as a '*hornito*.'

[1] Bailey, E. B., 'The Sgùrr of Eigg,' *Geol. Mag.*, Decade vi, vol. i, 1914, pp. 296-305.
[2] Mull Memoir, 1924, pp. 95-96, 112-113.
[3] Bailey, E. B., *op. cit.*, 1914, pp. 297-299.

Petrography

The Normal Rock-types.—The two rock-types which form the Kilmacolm lava are of very uniform character and do not differ materially from similar rocks elsewhere in the Scottish Carboniferous province. The basic type is a basaltic mugearite but, in the present paper, it will be designated as andesine-mugearite, which is the preferable name.

(a) *Andesine-mugearite*

The basic member of the flow is a typical andesine-mugearite. In hand specimen the rock is very dense and aphanitic, dark-grey to black in colour and with a marked platy structure due to the parallel orientation of the little felspar laths. Pale fawn to reddish weathering tints are common.

Under the microscope the rock consists predominantly of tiny (.15—.2 mm.), zoned laths of andesine in parallel orientation, abundant small grains and prisms of pale augite, subordinate iron-ore pseudomorphs after olivine and abundant grains of magnetite. The felspar laths are zoned and vary from andesine (An 40 per cent.) at the centre down to oligoclase-albite at the edges. They merge into the rather abundant felspathic mesostasis which has a refringence lower than that of Canada balsam and consists of oligoclase-albite (An 15 per cent.) with, probably, some orthoclase. The augite is fresh and forms small prisms. It shows a faint lilac-fawn colour and is a titaniferous variety. Measurements carried out on one rather larger individual on the Fedorow stage gave the following values :—

$$2V = 54° \qquad Z:c = 45°$$

This indicates the common titanaugite of the province.[1]

No fresh olivine occurs in the rock but it is represented by pseudomorphs in iron-ore, chlorite or, occasionally, granular silica. Magnetite, in small grains, is almost as abundant as the pyroxene, a character common to the mugearites of the region. The only additional constituents are a few shreds of biotite and rather numerous, long needles of apatite. Some haematite dust also occurs.

This rock has been analysed by Mr. B. E. Dixon and the result is set out in Table A, No. 1 together with analyses of Harker's type mugearite and the basaltic mugearite of the Inverkip composite lava.

[1] These values agree exactly with numerous determinations made on augites from the Tertiary and Carboniferous olivine-basalts of Scotland.

TABLE A

	A	1	B	C	2	D
SiO_2	48.40	48.04	49.24	58.30	63.89	60.56
Ae_2O_3	16.66	14.93	15.84	18.13	14.33	16.51
Fe_2O_3	8.54	12.16	6.09	3.59	4.75	3.12
FeO	2.85	2.33	7.18	0.90	1.14	3.77
MgO	4.85	3.45	3.02	2.36	1.30	0.61
CaO	7.44	6.81	5.26	3.11	1.98	3.08
Na_2O	3.42	4.74	5.21	5.83	5.85	5.57
K_2O	1.76	1.94	2.10	3.72	3.68	3.71
H_2O+	1.19	1.00	1.61	1.23	0.79	0.76
H_2O-	1.23	0.95	1.08	0.90	0.52	0.97
TiO_2	3.06	3.50	1.84	1.40	1.24	0.79
P_2O_5	0.49	0.55	1.47	0.40	0.59	0.19
MnO	—	0.14	0.29	0.23	0.21	0.39
Rest	0.07	0.04	0.30	0.16	0.08	0.28
Total	99.96	100.58	100.46	100.26	100.35	100.31

A. Basaltic mugearite, lower member of composite lava, Dunrod Hill, Inverkip, Renfrewshire. Anal. B. E. Dixon. Quoted from W. Q. Kennedy, *Geol. Mag.*, vol. xlviii, 1931, p. 171.

1. Andesine-mugearite, upper marginal member of composite lava, scarp below △ 519, Craigmarloch Wood, Kilmacolm, Renfrewshire. Anal. B. E. Dixon.

B. Mugearite, lower member of composite sheet, Druim na Criche, Skye. Anal. W. Pollard. Quoted from A. Harker, 'The Tertiary Igneous Rocks of Skye' (*Mem. Geol. Surv.*), 1904, p. 263.

C. Trachyandesite, lava, Ballagioch Hill, 3 miles west-south-west of Eglesham, Renfrewshire. Anal. E. G. Radley. Quoted from A. G. MacGregor in 'The Geology of North Ayrshire' (*Mem. Geol. Surv.*), 1930, p. 114.

2. Trachyandesite, interior of composite lava, scarp below △ 519, Craigmarloch Wood, Kilmacolm, Renfrewshire. Anal. B. E. Dixon.

D. Trachyandesite, intrusion, lesser peak of Meikle Bin, Campsie Fells. Anal. E. G. Radley. Quoted from 'The Geology of the Glasgow District' (*Mem. Geol. Surv.*), 2nd Edition, 1925, p. 183.

The Kilmacolm lava occupies a position intermediate between the two and approaches the type mugearite rather closely. It is, however, slightly poorer in alkalis and decidedly richer in TiO_2. The high ferric iron of the andesine-mugearite is a feature which it has in common with the Inverkip rock and results, in part, from an original richness in magnetite and in part from slight oxidation of the ores. The total iron is about the same in all three rocks. These

distinctions and resemblances are most clearly seen when the Niggli values are compared.

	si	al	fm	c	alk	k	mg
Basaltic mugearite (A)	125	25.5	42	21	11.5	.25	.45
Andesine-mugearite (1)	126	23	43	19	15	.20	.31
Mugearite (B)	135	25.5	42	15.5	17	.21	.30

(b) *Felspar-olivine-augite-phyric trachyandesite*

The acid member of the composite lava is a pale grey to reddish rock, rather coarser grained than the mugearite and with many small phenocrysts of flesh-coloured felspar, black augite and iron-ore pseudomorphs after olivine, set in a light felspathic groundmass.

Under the microscope the numerous, small (up to 2 mm. in diameter) phenocrysts are found to consist predominantly of acid andesine (An 30-35 per cent.), sometimes strongly zoned with oligoclase margins. The euhedral pyroxenes are usually somewhat smaller and rarely exceed 1 mm. They consist of a light-green variety of diopside quite distinct from the pyroxene of the mugearite. The following values were obtained on the Fedorow stage :—

$$2V = 60° \qquad Z : c = 39°$$

No fresh olivine occurs in the rock but its former presence is indicated by typical pseudomorphs in iron-ore, chlorite and granular silica. The porphyritic constituents often form small glomero-porphyritic groups in which the internal boundaries of the minerals are anhedral. In one slice the diopside was seen to form an intergrowth with a euhedral crystal of oligoclase-andesine.

The abundant groundmass is orthophyric and predominantly felspathic with abundant small tabular crystals of acid plagioclase and orthoclase, a few grains and prisms of diopside, some magnetite and rather abundant, stout, needles of violet coloured apatite. A few inconspicuous shreds of biotite also occur. All the felspar has a refringence lower than that of Canada balsam and the presence of both oligoclase-albite (An 15 per cent.) and orthoclase has been established although it is impossible to state definitely their relative proportions. They appear to be present in roughly equal amounts.

The analysis of this rock by Mr. B. E. Dixon is given in Table A No. 2 together with analyses of two other Scottish Carboniferous trachyandesites. The Niggli values are as follows :—

	si	al	fm	c	alk	k	mg
Trachyandesite (C)	203	37	24.5	11	27.5	.30	.50
Trachyandesite (2)	255	33.5	26	8.5	32	.30	.30
Trachyandesite (D)	224	36	23.5	12	28.5	.30	.14

Mineralogically the three rocks are very similar as they all contain phenocrysts of plagioclase, augite and olivine set in a felspathic groundmass in which oligoclase-albite and orthoclase are present in roughly equal proportions. Chemically the Kilmacolm rock is distinguished from the other two by its higher silica and ferric iron and its lower alumina and lime. This difference is probably due

largely to the fortuitous variation in composition which characterises all porphyritic rocks. In addition, the porphyritic plagioclase of the other two rocks is a more basic variety (labradorite) while their pyroxene is a titanaugite instead of a diopside.[1]

The Abnormal Mixed Rocks.—As pointed out above (p. 85), where the trachyandesite comes into contact with the mugearite the latter has been assimilated with the production of hybrid types, intermediate in nature between the parent rocks. This is a point of considerable interest as records of assimilation of basic igneous rock by acid magmas, under effusive conditions, are comparatively rare and have a direct bearing on certain problems of petrogenesis. Only three well authenticated cases are known to the writer.

Iddings[2] has described the assimilation of basalt lava by a later flow of rhyolite in the Yellowstone region of Montana. A rather similar case is that described by Fenner[3] from the Novarupta dome in the Katmai region of Alaska where rhyolite magma has assimilated basic andesite. In both cases the resulting products are banded and mixed rocks whose hybrid nature is obvious in the field. Lately it has been shown by van Bemmelen and Esenwein[4] that the latite plug in the crater of the volcano Tanggamoes in Sumatra is a hybrid rock which has formed through the assimilation of basalt by a plagio-liparitic magma. The hybrid rock is estimated to consist of 29 per cent. basalt and 71 per cent. plagio-liparite.

According to Iddings[5] the process involves *melting* of the basic rock. He says :—

"... These various modifications of the rock grade into one another and intermingle in streaks without any distinct line of demarcation between them. The appearance is that of a completely fused mass of somewhat differently constituted materials. In places in this vicinity the spherulitic rhyolite incloses fragments of basalt ... It is evident, both from the occurrence of large fragments of basalt completely surrounded by rhyolite and from the microscopical character of the rocks, that the rhyolite fused the basalt and is the more recent eruption. The rhyolite must have been in a completely fused condition when it came in contact with the basalt, so that its temperature was higher than that of the melting point of basalt. The latter was not melted at any considerable distance from the contact with rhyolite, but behaved as though dissolved in the rhyolite magma along the contact."

This idea of actual '*melting*' of the basic rock by the acid magma is also expressed by Fenner in his description of the phenomena at Novarupta and he uses it as an argument against Bowen's theory of magmatic evolution.[6]

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[1] For descriptions of the trachyandesites from Ballagioch Hill and Meikle Bin see A. G. MacGregor in 'The Geology of North Ayrshire' (*Mem. Geol. Surv.*), 1930, p. 116, and E. B. Bailey in 'The Geology of the Glasgow District' (*Mem. Geol. Surv.*), 2nd Edition, 1925, p. 183.

[2] Iddings, J. P., 'The Geology of the Yellowstone National Park,' Monograph 32, Pt. 2, *U. S. Geol. Surv.*, 1899, pp. 430-432.

[3] Fenner, C. N., 'The Katmai Magmatic Province,' *Journ. Geol.*, vol. xxxiv, 1926, p. 740; 'The Crystallization of Basalts,' *Am. Journ. Sci.*, vol. xviii, 1929, pp. 251-252; 'The Residual Liquids of Crystallizing Magmas,' *Mineralogical Mag.*, vol. xxii, 1931, pp. 558-559.

[4] van Bemmelen, R. W. and P. Esenwein, 'De liparitische eruptie van den Tanggamoes-vulkan,' *Dienst v.d.Nederlandsch-Indie, Weten. Mede.*, No. 22, 1932, pp. 38 and 62.

[5] Iddings, J. P., *op. cit.*, 1899, pp. 430 and 432.

[6] Fenner, C. N., *Am. Journ. Sci.*, vol. xviii, 1929, pp. 251-252; *Mineralogical Mag.*, vol. xxii, 1931, p. 558.

In the Kilmacolm lava no trace of actual melting is apparent either in the field or under the microscope. On the contrary, the phenomena indicate dissolution of the basic rock in the acid magma and scattering of the constituents throughout the fluid mass. It is beyond dispute that *the solid mugearite, where enveloped and assimilated by the trachyandesite magma has retained, as a whole, its solid, crystalline character during the mixing process.*

The characteristic feature of the transition zones which separate the central trachyandesite from the upper and lower mugearites, is the extremely inhomogeneous nature of the rocks concerned. The acid rock becomes basified and develops a patchy and streaky appearance due to the incorporation of mugearitic material and, at the same time, encloses many relict enclaves of mugearite in all stages of digestion. A feature which distinguishes the mugearite enclaves from the normal mugearite of the flow is the presence of small porphyroblasts of oligoclase-andesine similar in composition to the phenocrysts of the trachyandesite. There can be little doubt that these porphyroblasts have developed in the solid enclaves and result from the influence of the acid magma just as in the case of certain plutonic rocks.[1]

Under the microscope, the fine-grained nature of the rocks makes it extremely difficult to determine the mineralogical transformations involved in the process of hybridization, and only the general effect can be discussed. All the enclaves, even though they retain, in general, their compact mugearitic nature, are strongly rounded and resorbed (Plate VIII, fig. 4). In a more advanced stage of alteration the enclave becomes thoroughly disintegrated throughout and drawn out into long streaks, due to flow movements in the fluid trachyandesite magma. Finally the component minerals are distributed through the acid magma and all that remains of the original xenolith is a basified patch of trachyandesite enriched in granules of pyroxene and iron ore (Plate VIII, fig. 6).

The rocks are too fine grained to determine whether the augite of the mugearite undergoes recrystallization and change of composition during the process. The disintegration and strewing about of the pyroxene and iron-ores convey the impression, however, that the main effect operates on the felspar of the basic rock inducing both change of composition and of volume.

The phenomena recall the disintegration and strewing of the component minerals of a hornfels described by Goldschmidt[2] from the Christiania (Oslo) region.

According to Bowen[3], who has discussed in detail the behaviour of inclusions in igneous magmas, no magma can dissolve inclusions of more basic rock but can only react with them and convert them into phases with which it is itself saturated. The reactions involve

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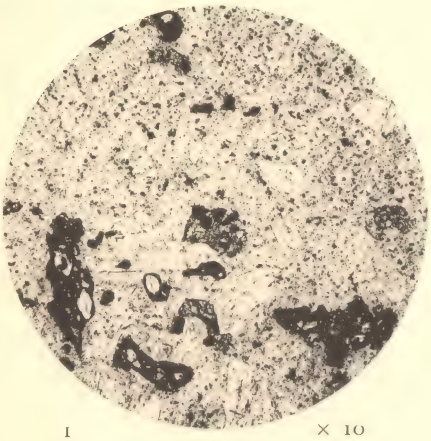
[1] MacGregor, A. G., and W. Q. Kennedy, 'The Morvern-Strontian Granite,' 'Summary of Progress' for 1931, Pt. ii (*Mem. Geol. Surv.*), 1932, p. 114.

[2] Goldschmidt, V. M., 'Die Kontaktmetamorphose im Kristianiagebiet,' Vidensk. Selsk. Skr., I, Mat. Natur. Kl., 1911, pp. 107-108.

[3] Bowen, N. L., 'The Evolution of the Igneous Rocks,' Princeton, 1928, pp. 198-199.



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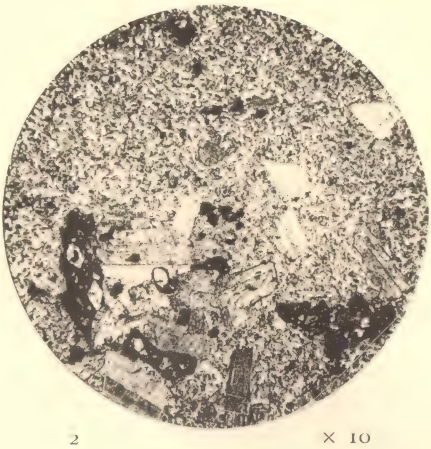

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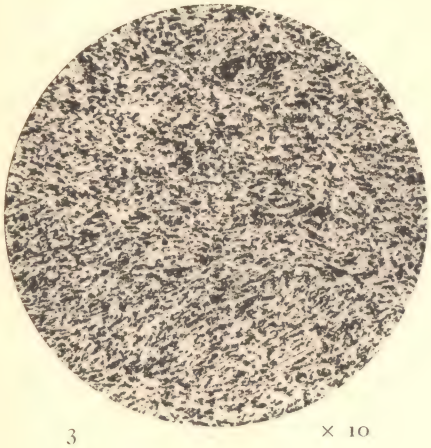

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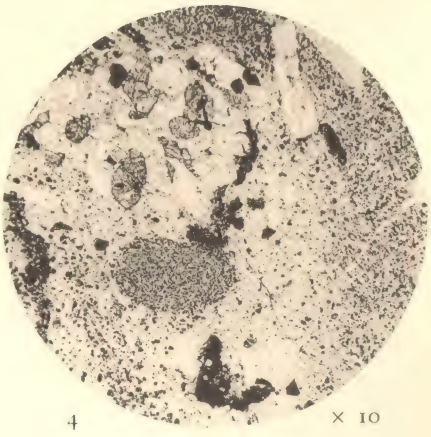

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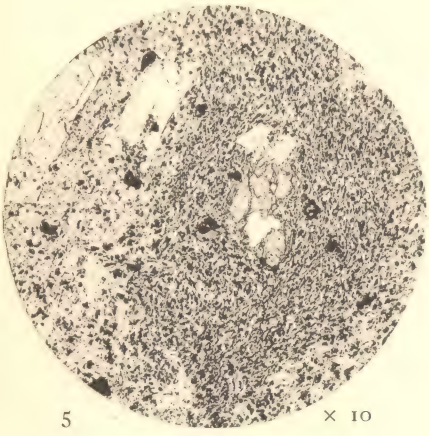

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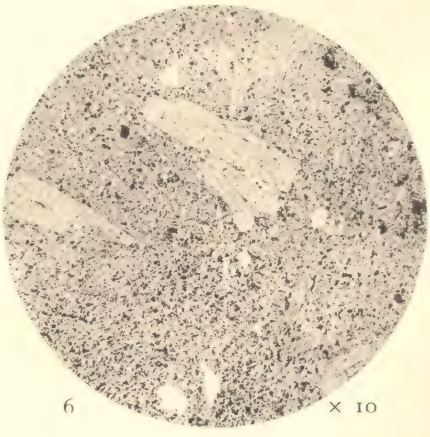

6 × 10

ROCKS FROM THE KILMACOLM COMPOSITE LAVA.

volume changes which lead to disintegration of the enclave and strewing of its component minerals throughout the invading magma.

There can be little doubt that some process similar to that postulated by Bowen has operated in the case of the Kilmacolm lava. There is no trace of melting of the mugearite and it is clear that the basic inclusions have remained essentially solid and crystalline during the mixing process. The acid magma has incorporated the constituents of the mugearite, in a crystalline state, with the production of hybrid rocks intermediate in composition between the two parent rocks.

In conclusion it must be pointed out that, while the intimate nature of the field association indicates a close community of origin for the mugearite and trachyandesite magmas, there is no evidence that they co-existed in some intercrustal magma basin. As in the case of all other composite lava flows and minor intrusions it is equally possible, and even more probable, that the differentiation actually occurred as the magma moved bodily up the throat of the volcano. If this conception of differentiation during movement is adopted the whole problem of composite intrusion and extrusion is greatly simplified.

Explanation of Plate VIII

Photomicrographs of Rocks from the Kilmacolm Lava Flow

Fig. 1. Normal trachyandesite, magnified 10 diameters, ordinary light.

Glomeroporphyritic group consisting of oligoclase-andesine, diopside and iron-ore and silica pseudomorphs after olivine in an orthophyric groundmass of small tabular crystals of acid plagioclase and orthoclase.

Fig. 2. Same field as Fig. 1, between crossed nicols.

Fig. 3. Andesine-mugearite, magnified 10 diameters, ordinary light.

Small, flow-orientated laths of zoned andesine together with abundant grains of pyroxene and iron-ore. Some of the latter represent olivine pseudomorphs.

Fig. 4. Xenolithic trachyandesite, magnified 10 diameters, ordinary light.

A compact, resorbed enclave of fine-grained mugearite is present about the centre of the field while a more highly altered and streaked out example occurs on the right. The highly refringent grains are augite.

Fig. 5. Mugearite xenolith, magnified 10 diameters, ordinary light.

The basic enclave is undergoing intense disintegration and the component minerals are strewn about in the trachyandesite.

Fig. 6. Hybrid rock, magnified 10 diameters, ordinary light.

A very advanced stage in the mixing process. The original mugearitic material is represented by the enrichment in pyroxene and iron-ores visible in the lower part of the field.

V.—THE LOWER ORDOVICIAN GRAPTOLITE FAUNAS WITH SPECIAL REFERENCE TO THE SKIDDAW SLATES

BY

GERTRUDE L. ELLES, D.Sc.

Text-figures 1—13.

INTRODUCTION

RECENT collections of graptolites made by the officers of the Geological Survey and others in the Lake District and elsewhere have added considerably to our knowledge of the graptolite-faunas of the Lower Ordovician rocks, and modern methods of study have indicated, more clearly than before, the way in which these may be interpreted in order to aid stratigraphical work; hence it is now possible to make some corrections and extend the scope of the paper published in 1904 on the graptolite zones in the Arenig rocks of Wales,[1] by a more complete analysis of the Lower Ordovician graptolite faunas as a whole, and especially as regards the faunas included up to the present in the Zone of *Didymograptus extensus*; it can now be shown that there are at least four sub-faunas within this zone, and that these have a definite relationship to each other as regards the evolutional condition of the graptolites constituting the typical sub-assemblages. A mere graptolite list of the old-fashioned type is apt to be very misleading unless the relative abundance of the various forms is noted, and unless too, some indication be given of the state of evolution of the different fossils. Without this, the solitary occurrence of a graptolite is recorded as of equal importance with its occurrence in abundance at higher or lower horizons, and early and late mutations are ignored, though their occurrence might be of considerable significance to the stratigrapher.

A graptolite zone has been defined as a belt of strata containing a definite assemblage of graptolites of which one characteristic species is chosen as the index,[2] but from the point of view of the modern stratigraphical palaeontologist it is possible to place a further meaning upon this assemblage; it should indicate a concentration of forms in a certain state of evolution, and thereby its value is intensified. This point has not been stressed sufficiently in the past, and hence there has been much misunderstanding and misinterpretation of the facts of graptolite distribution in time.

Within the Lower Ordovician rocks, for example, it is not the occurrence of any particular *Clonograptus*, *Loganograptus*, or

[1] Elles, G. L., 'Some Graptolite Zones in the Arenig Rocks of Wales,' *Geol. Mag.*, 1904, pp. 199-211, figs. (geol. maps).

[2] Elles, G. L., 'The Graptolite Faunas of the British Isles. A Study in Evolution,' *Proc. Geol. Assoc.*, vol. xxxiii, 1922, p. 199.

Dichograptus that is significant; individuals of all these genera have a long range in time, although as a rule with some degree of stipe reduction, but what is important is that there is a concentration of many-branched graptolites at a particular horizon implying that in the general evolution of the Graptoloidea, the majority have not reached beyond this evolutional stage at this horizon. It is this horizon that has been termed the Zone of *Dichograptus* or the Zone of many-branched graptolites. The recognition of this horizon does not imply that many-branched graptolites only occur at that horizon, for both *Loganograptus* and *Dichograptus*, and more rarely *Clonograptus*, occur fairly frequently as individuals at higher horizons, but they are then accompanied by a concentration of forms in a more advanced state of evolution.

At a higher horizon for example, there is a concentration of forms in the *Tetragraptus* stage, the trend of stipe- or branch-reduction having by this time resulted in the production of many four-stiped graptolites; the horizon of this *Tetragraptus* concentration may moreover be readily subdivided into two, a lower in which the stipes grow horizontally, which is here called the lower Subzone of *Tetragraptus*, and an upper in which the stipes are reclined, these forms having advanced further towards the attainment of the scandent position of growth. This constitutes the upper Subzone of *Tetragraptus*. In condensed successions such as that of the Lévis Shales of Quebec, an overlap of these two subzones is only to be expected, but there remains the horizon of concentration of *Tetragraptus* above that of the concentration of the many-branched graptolites. At the lower of these two horizons, many-branched graptolites are still much in evidence, and the horizon is probably best regarded as a subzone at the top of the Dichograptus Zone. At the higher horizon the many-branched forms are not so common, and the reclined *Tetragrapti* are accompanied by some horizontally-growing two-stiped graptolites obviously very closely related to the earlier horizontally-growing *Tetragrapti*. These *Didymograpti* indicate a still further advance along the trend of stipe-reduction, but the horizon of maximum concentration of graptolites in this stage of evolution has not yet been reached, it belongs to a still higher horizon.

These two-stiped graptolites however quickly become the most conspicuous elements in the fauna, and therefore above the horizon of concentration of *Tetragraptus*, there is found the horizon of concentration of horizontally-growing two-branched graptolites, *i.e.* the horizon of concentration of the extensiform *Didymograpti*.

The beds containing the assemblages of graptolites falling under this head again divide themselves into two; a lower horizon characterized by long slender *Didymograpti* of the type of the true *Didymograptus extensus*, forming the Zone of *Didymograptus extensus*, and a higher horizon characterized by much thicker *Didymograpti* of the type of *Didymograptus hirundo*, the Zone of *Didymograptus hirundo*. There appears however to be a very complete series of

transients between *D. extensus* on the one hand and *D. hirundo* on the other, many of which have received special names as distinct species, the best known perhaps being *D. nitidus* (Hall).[1]

The numerous careful collections made in the Skiddaw Slates seem to show beyond doubt, as has for long been suspected not only in the Lake District but in other areas, that the Zone of *Didymograptus extensus* is capable of a considerable degree of subdivision when the beds are spaced out. When the succession is much condensed these will of necessity be found to overlap. The higher of the two subzones with conspicuous *Tetragrapti* seems best regarded as the basal subzone of the Zone of *Didymograptus extensus*, since in it, the earliest forms of *D. extensus* undoubtedly make their appearance. The horizon of concentration of *Tetragraptus* thus characterizes the top of the Dichograptus Zone and the base of the *Didymograptus extensus* Zone.

This upper Subzone (a) of *Tetragraptus* is indicated by the entrance of reclined *Tetragrapti*, accompanied by many horizontally-growing *Tetragrapti*, and by the appearance of small extensiform *Didymograpti*.

At a higher horizon there is a most conspicuous concentration of slender extensiform *Didymograpti* still, however, accompanied by numerous horizontal and reclined *Tetragrapti*. The *Didymograptus* most distinctive of this horizon, which has a wide distribution in space and is an easily recognized form, is *Didymograptus deflexus* (Fig. 13) and this may therefore give its name to the horizon. The Subzone (b) of *Didymograptus deflexus* is therefore indicated by the abundance of the true *D. extensus*, accompanied by *D. extensus-nitidus* transients, the presence of *D. deflexus*, and many horizontal and reclined *Tetragrapti*.

Still higher there may be recognized another horizon which may be termed the Subzone (c) of *Didymograptus nitidus* (*sensu stricto*). This is indicated by an abundance of *D. nitidus* (*sensu stricto*) accompanied by numerous *D. extensus*, by the entry of relatively small tuning-fork *Didymograpti*, by the appearance of scandent *Tetragrapti* (*Phyllograptus angustifolius*), and by the earliest Diplograptid, *Glyptograptus dentatus*.

Higher again comes the horizon which may be termed the Subzone (d) of *Isograptus* [*Didymograptus*] *gibberulus*. The subzone fossil makes its appearance in the subzone below, though at first it is not a conspicuous element in the fauna, but at this higher horizon it is frequently very abundant and is such a striking form that it constitutes a good index-fossil. At this horizon it is accompanied by numerous *D. nitidus-hirundo* transients,[2] and also by a few *D. hirundo-nitidus* transients.[3] Locally, tuning-fork *Didymograpti* transients between *D. protobifidus* sp. nov., and *D. bifidus* (*sensu stricto*) are fairly abundant.

The higher horizon of the extensiform *Didymograpti*, the Zone of

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[1] See p. 100.
[2] Nearer *D. nitidus*.
[3] Nearer *D. hirundo*; see p. 100.

Didymograptus hirundo which now succeeds, is marked by the appearance of the true broad *D. hirundo*, accompanied by many *D. hirundo-nitidus* transients, locally *D. bifidus-protobifidus* is common and a few *D. bifidus* (*sensu stricto*) occur. *Azygograptus suecicus* is an abundant form at this horizon, as are also scandent *Tetragrapti* (*Phyllograpti*). It would appear that this is the horizon of the true *Phyllograptus typus*, though the forms commonly referred to this species are not Hall's species which is a large and most characteristic *Phyllograptus*.

The next distinctive geological horizon is the Zone of *Didymograptus bifidus* (*sensu stricto*). Here a striking feature is the preponderance of *Didymograpti* of the tuning-fork type over those of extensiform type though a few of these occur, some (*D. acutidens*) showing the early indication of the *Leptograptus* type of theca.

The appearance of the earliest tuning-fork graptolites fairly high up within the Zone of *Didymograptus extensus*, in Subzone (c) of *D. nitidus* (*sensu stricto*), calls for special comment, as much misinterpretation has resulted from its occurrence. One of these little forms, the *D. protobifidus* of the present paper, has quite commonly (and quite erroneously) been referred to *D. bifidus* (Hall) and hence much confusion has arisen over the position of the Zone of *D. bifidus* and the graptolite-assemblage characteristic of it. The form here described as *D. protobifidus*, since it is the ancestral form of the true *D. bifidus*, naturally presents some features in common with it. It is however quite clearly not the form characteristic of the Zone of *D. bifidus*, which I have myself collected from the type-locality, and which occurs typically above the Zone of *D. hirundo*, though a few individuals make their appearance within that zone (see Fig. 5). At its first appearance it is a small form, which in its initial stages closely resembles the true *D. bifidus*, but whereas in *D. bifidus* the thecae increase steadily in length and in the amount of their overlap so that the stipe widens steadily and conspicuously throughout its length, in the earliest form the characteristics of the early thecae are retained throughout the length of the stipe, so that there is only a little increase in breadth ; it soon, however, begins to take on what may be termed ' *bifidus* characters ' and to show some increase in overlap and some increase in breadth, but the mature stipes are commonly short, and even when long, as sometimes happens, are always narrower than in the true *D. bifidus*, even in the latest transients (see Fig. 4) ; these forms may also be regarded as early mutations of *D. bifidus*. The higher the beds, the closer the approach to *D. bifidus* itself. There are in fact, innumerable transients between the two extreme types, but not till the horizon of the Zone of *D. hirundo* is there found a form that might be referred to the true *D. bifidus* ; at this horizon it is commonly accompanied by a number of forms which have still not reached so advanced a stage. These *D. protobifidus-bifidus* transients do not seem to be quite universally distributed, they are rather more local in their occurrence than the other graptolites characteristic of these horizons.

Description of a New Species

Didymograptus protobifidus sp. nov.

Text-figures 1—3, page 110

1868. *Didymograpsus geminus* (Hisinger), Nicholson, *pars*, *Quart. Journ. Geol. Soc.*, vol. xxiv, pp. 134-5, pl. v, fig. 10?

1870. *Didymograpsus geminus* (Hisinger), Nicholson, *pars*, *Ann. Mag. Nat. Hist.*, Ser. 4, vol. v, p. 346, fig. 6b?

1898. *Didymograptus indentus*, var. *nanus* Lapworth, Elles, *pars*, *Quart. Journ. Geol. Soc.*, vol. lv, p. 511.

1901. *Didymograptus nanus* Lapworth, Lapworth, Elles and Wood, *pars*, *op. cit. infra*,[1] p. 47, pl. iv, fig. 5d.

Description.—Rhabdosome commonly small, stipes ranging from 1—2 cm. in length, narrow at origin, and increasing very slightly in width to a maximum of 1.3 mm., either running parallel or diverging in the manner of *D. bifidus*. Sicula conspicuous, slender. Thecae 13 in 10 mm., free ½ their length, inclined at a low but variable angle, slightly curved distally, with apertural margins slightly oblique to the general direction of the stipe.

Remarks.—This species seems to have been very commonly confused with *D. nanus* Lapworth, which it may resemble in general shape and size, and with which it was somewhat doubtfully included in the Monograph of British Graptolites.[1] It is however distinct in several particulars; the width of the stipes is less uniform than in *D. nanus*, and the thecae are differently set, so that not only are they more numerous in a given unit of length, but the apertural margins are oblique to the general direction of the stipe, instead of being perpendicular as they are in both *D. nanus* and *D. indentus*, and occupy a small portion of the total width. The thecae are essentially of the same type as those seen in the young stages of *D. bifidus*, but they never attain the curvature or degree of overlap seen in the mature thecae of *D. bifidus* or its ally *D. artus*.

Horizon.—Middle to Upper Skiddaw Slates (Zone of *D. extensus*, two upper subzones; Zone of *D. hirundo*; Zone of *D. bifidus*).

Localities.—Outerside; Barf; Glenderamakin Valley; Scree ¼ mile S. of Mungrisdale, 250 yds. E. of Hazelhurst; White Horse Bent, Force Dub Slate Quarry; also other Lake District localities.

[1] Lapworth, C., G. L. Elles, and E. M. R. Wood, 'A Monograph of British Graptolites,' pt. i, 1901, p. 47, pl. iv, fig. 5, *Palaeont. Soc.* Of the specimens figured, 5a, 5b, 5c, 5e, 5g are now retained as *D. nanus*; 5d is *D. protobifidus*; 5f and 5h are now regarded as *D. protobifidus-bifidus* transients.

Table shewing main Differences in common tuning-fork Graptolites in the Skiddaw Slates

	D. indentus (Hall)	*D. nanus* Lapworth[1]	*D. protobifidus* sp. nov.[2]	*D. bifidus* (Hall)
Length of rhabdosome	1-3 cm.	rarely above 1 cm.	1-2 cm.	2-4 cm.
Width of stipe	about 1.2 mm.	1 mm.	1-1.3 mm.	3 mm. (maximum)
No. of thecae in 10 mm.	8-10	10	13	13-15
Thecal inclination, curvature and overlap	constant inclination at low angle, overlapping ½ their length		angle of inclination increasing distally, slight curvature, overlap ½ length	great increase in amount of thecal curvature towards distal end, overlap ¾ length or more
Thecal apertural margin	perpendicular to direction of stipe		oblique to direction of stipe	very oblique

The Lower Ordovician Extensiform Graptolites

The extensiform graptolites of the Lower Ordovician are a very conspicuous element in its graptolite fauna and, as has been noted by Tullberg,[3] Törnquist,[4] Ruedemann[5] and others, the various forms present many features in common, rendering them difficult of separation; a careful study of their field occurrences in the Skiddaw Slates and in the Phyllo[graptus]-Tetragraptus Beds in Sweden suggests strongly that they may form a related series continuous in time; and their occurrence in the Lévis Shales confirms this view though there is more overlapping there, in Quebec, than in the European localities.

Thus, there may be recognized as heralding the incoming of the *Didymograpti*, a small form of *D. extensus* type which is characteristically narrow and almost uniform in width; it is closely related to *D. holmi* Törnquist and may be the same form, or else it is just a young *D. extensus*. It is quickly succeeded by the true *D. extensus*

[1] *D. nanus* is possibly just a late mutation of *D. indentus*.

[2] There are numerous transients linking *D. protobifidus* with the real *D. bifidus* (Figs. 4, 5).

[3] Tullberg, S. A., 'Några *Didymograptus*-arter i undre graptolitskiffer vid Kiviks-Esperöd,' *Geol. Fören. Stockh. Förhandl.*, bd. v, no. 2, 1880, p. 39.

[4] Törnquist, S. L., 'Researches into the Graptolites of the lower Zones of the Scanian and Vestrogothian *Phyllo-Tetragraptus* Beds, I,' *Lunds Univ. Aarsskrift*, bd. xxxvii, afd. 2, no. 5, 1901, pp. 1-26, pl. i-iii; also 'II' *ibid.*, bd. xl, afd. 2, no. 2, 1904, pp. 1-27, pl. i-iv.

[5] Ruedemann, R., 'Graptolites of New York,' Part I, *Mem. N.Y. State Mus.*, no. 7, 1904, pp. 455-803.

(Hall *non* Törnquist), a *Didymograptus* (see Figs. 6, 7) which frequently attains several centimetres in length and widens gradually from its origin for the first 12 mm., and almost imperceptibly afterwards till it attains the maximum width of 1.6 mm.; thereafter it is of uniform breadth. At a slightly higher horizon but with some overlapping, there appears another form which widens more rapidly than the true *D. extensus* but has not yet acquired all the characteristics of the true *D. nitidus* (Hall). This is the form figured by Törnquist as *D. extensus* but it seems more correctly regarded as a *D. extensus-nitidus* transient. All these three forms have often hitherto been included in *D. extensus*. Then the true *D. nitidus* (Hall) makes its first appearance (Fig. 8) and is usually a very abundant form; it is still accompanied by some of the lower extensiform types. Then there follows, again with some overlapping in the different forms, a succession of transients between *D. nitidus* and *D. hirundo*, the greater number approaching more and more to the *D. hirundo* type, the higher they are in the succession. One of the earliest of these is *D. patulus* (Hall *pars*, *non* Törnquist), a graptolite (Fig. 9) that has been a puzzle to many palaeontologists who have realised its nearness to *D. nitidus*, which yet had certain distinctive features. These features are the beginning of what may be termed '*hirundo* characters' perhaps most conspicuously shown in the region of the proximal end in the later forms and in the thecal characters; but in the *D. patulus* transient in the increase in width and in general greater rigidity of the stipes. The next transient has stipes very similar to *D. patulus*, but the proximal end shows a definite approach to the 'closed up' type of *D. hirundo*, as distinct from the 'open' type of *D. extensus*, and a definite widening of the thecae towards their apertures. This is *D. suecicus* Tullberg (Fig. 10), a common form at a certain horizon alike in the Lévis Shales, the Phyllo-Tetragraptus Shales and the Skiddaw Slates. Another common transient still nearer to *D. hirundo*, which might indeed be described as a 'narrow *hirundo*,' is fairly abundant with *D. suecicus* in the Lévis Shales but ranges definitely beyond it in the Phyllo-Tetragraptus Shales and in the Skiddaw Slates; this is *D. praenuntius* Törnquist (Fig. 11). Above it as a whole, though with some overlapping, is found the true *D. hirundo*, a most characteristic species (Fig. 12).

The related series therefore seems to run:—*D. extensus* small (*D. holmi* ?) –> *D. extensus* (*sensu stricto*) –> *D. extensus-nitidus* (transient) –> *D. nitidus* (*sensu stricto*) –> *D. patulus* (transient) –> *D. suecicus* (transient) –> *D. praenuntius* (transient) –> *D. hirundo* (*sensu stricto*).

Zonal Assemblages in the Skiddaw Slates

Zone of Bryograptus kjerulfi

Bryograptus kjerulfi Lapworth and various mutations with fewer stipes collectively termed *B. cumbrensis* Elles.

Zone of Dichograptus (*Many-branched Graptolites*)

Concentration of many-branched Dichograptids, *i.e.*, *Clonograptus flexilis* (Hall), *Clonograptus sp.* ; *Dichograptus octobrachiatus* (Hall) often of large size, *Loganograptus logani* (Hall) unaccompanied by those with fewer stipes or branches.

Lower Subzone of *Tetragraptus* (horizontal)[1]

Entrance of horizontally-growing *Tetragrapti* of the general type of *T. quadribrachiatus* (Hall), with *T. headi* (Hall), *T. crucifer* (Hall) and *Azygograptus lapworthi* Nicholson. Many-branched Dichograptids still common.

Zone of Didymograptus extensus

D. extensus (Hall), *Tetragr. serra* (Brongniart), *T. amii* Lapworth MS., Elles and Wood, and Dichograptids, usually lacking the full complement of stipes, range throughout.

(a) Upper Subzone of *Tetragraptus* (reclined)

Entrance of reclined *Tetragrapti*, *T. amii* Lapworth MS., Elles and Wood, *T. serra* (Brongniart), *T. bigsbyi* (Hall), still accompanied by *T. quadribrachiatus*, *T. headi*, *T. crucifer*. Entrance of small extensiform *Didymograpti*, *D. extensus* (Hall) or *D. holmi* ? Törnquist. [*Azygograptus hicksi* Hopkinson, common horizon for Dendroid graptolites].

(b) Subzone of *Didymograptus deflexus*

D. extensus (Hall) *sens. strict.*, abundant with *D. extensus-nitidus* transients, *D. deflexus* Elles and Wood abundant, *D. v-fractus* Salter, *T. amii*, *T. serra*, *T. quadribrachiatus* (mostly small), *T. bigsbyi*, *T. pendens* Elles, *Hologr. deani* Lapworth MS., Elles and Wood, *Azygograptus eivionicus* Elles.

(c) Subzone of *Didymograptus nitidus*

D. nitidus (Hall) abundant, with abundant *D. extensus* and numerous *D. nitidus-hirundo* transients (*D. patulus* Hall *pars*), some *D. extensus-nitidus* transients, *D. uniformis* Elles and Wood, *D. affinis* Nicholson (rare), *D. simulans* Elles and Wood, *Isograptus* [*Didymograptus*] *gibberulus* (Nicholson) rather rare ; *D. nicholsoni* Lapworth. Common horizon for entrance of small tuning-fork *Didymograpti*, *i.e.*, *D.* cf. *indentus* (Hall), *D. protobifidus* Elles sp. nov. Entrance of Diplograptids, *Glyptogr. dentatus* (Brongniart). *Tetragrapti* still fairly common, entrance of scandent forms, *Phyllograptus angustifolius* (Hall), *P. anna* (Hall), *P. ilicifolius* (Hall) [*Glossograpti*].

[1] Occurring at the top of the Dichograptus Zone.

(d) Subzone of *Isograptus* [*Didymograptus*] *gibberulus*

I. gibberulus abundant, also *D. nitidus*, *D. extensus* and the *D. nitidus-hirundo* transients, *i.e.*, *D. patulus*, *D. suecicus* Tullberg, *D. praenuntius* Törnquist, *D. uniformis*, *D. protobifidus-bifidus* transients; *T. serra*, *T. amii*, *Phyllogr. angustifolius* (abundant), *P. ilicifolius*; *Glyptogr. dentatus* (common); *Azygogr. suecicus* Moberg (rather rare); *Cryptogr. antennarius* (Hall), *C. hopkinsoni* (Nicholson) both fairly abundant; *Trigonogr. ensiformis* (Hall).

Zone of Didymograptus hirundo

D. hirundo Salter abundant, accompanied by many *D. hirundo-nitidus* transients, *i.e.*, *D. praenuntius*, *D. nitidus*, *D. uniformis*, *Phyllogr. typus* (Hall), *P. angustifolius*, *P. ilicifolius*; *Azygogr. suecicus* (abundant); *Tetragrapti* very rare; *D. bifidus* (Hall) rare, but late transients of *D. protobifidus-bifidus* locally abundant; *Glyptogr. dentatus*.

Zone of Didymograptus bifidus (sensu stricto)

D. bifidus (Hall) *sens. strict.*, very abundant, accompanied by *D. artus* Elles and Wood, *D. nanus* Lapworth, *D. stabilis* Elles and Wood, *D. acutidens* Lapworth MS., Elles and Wood, and many *Glossograpti* (locally).

The graptolites listed above are those usually met with at the horizon indicated, any special abundance or rarity is recorded. Some forms as yet unrecorded from the Skiddaw Slates but common at the horizon in other British localities are placed in square brackets.

As indicating the Zone of *D. extensus* when graptolites are not sufficiently numerous to make division into subzones advisable, there may be noted the presence of long slender *Didymograpti* of the general type of *D. extensus* and *D. nitidus* with possibly some *D. nitidus-hirundo* transients: other *Didymograpti* likely to be present are *D. deflexus*, *D. v-fractus* and *Isograptus gibberulus*; *Tetragrapti* of both reclined type (*T. serra*) and horizontal type (*T. quadribrachiatus*) will almost certainly be found, and the scandent *Phyllograpti* if anywhere near the top of the zone. *Clonograpti* will almost surely be present if the horizon is near the base of the zone, and *Loganograptus* and *Dichograptus* may occur at any horizon within the zone. It should, however, be noted that these forms are not as a rule as large as those that occur at lower horizons, and have commonly not developed their full complement of stipes.

Distribution

Dixon is mistaken in thinking that the evidence of the graptolites in the Skiddaw Slates is contradictory;[1] if properly interpreted in

[1] Dixon, E. E. L., *in* 'The Geology of the Whitehaven and Workington District' (*Mem. Geol. Surv.*), 1931, pp. 31-37.

the manner indicated earlier in this paper the evidence is entirely satisfactory. His idea that the graptolite evidence indicates that the beds at Barf and Outerside are of the same age is not warranted by the facts now available; the graptolite assemblages in the two localities suggest clearly that the Outerside fauna is a higher fauna as a whole than that at Barf (see p. 104). Dixon does not believe in the existence of the Tremadoc Beds in the Lake District, but it is difficult to ignore the evidence afforded by *Bryograptus kjerulfi*. *Bryograptus kjerulfi* occurs in Norway (the type locality) in the upper part of the Dictyonema Shales (Bryograptus Beds) not far above the Zone of *Dictyonema norvegica* and is known from no other horizon. In the Skiddaw Slates it has only been recorded from Barf at the south end of Barf Hill, in the Loweswater Flags; in view of the very disturbed state of the beds at that locality it does not appear impossible that beds of Tremadoc age are nipped in there along a thrust. I have for a long time believed this to be the case. The mutations of *Br. kjerulfi* with fewer stipes are undoubtedly found at higher horizons.

Very little attention need really be paid to the solitary records of *Dicellogr. moffatensis* (Carruthers) from Barf[1] or to the one obscure little *Glossograptus* recorded doubtfully as *G. fimbriatus* (Hopkinson).[2] The latter might equally well be a young *G. acanthus* Elles and Wood, a quite common form in the Zone of *D. extensus* in co. Mayo, Ireland, but unknown when the Skiddaw Slate paper[3] was published, and the record has persisted as *G. fimbriatus*. The Barf specimen of *Dicellogr. moffatensis* is still more dubious, as it has disappeared, and other specimens from the Skiddaw Slates referred to this form were not graptolites at all. There is no authenticated record of any *Dicellograptus* below the true horizon of *Didymograptus bifidus*.

There does not appear to be any valid reason for doubting the occurrence of beds belonging to the Zone of *Dichograptus*, since this zone appears to be developed across a wide belt of country ranging from Gate Gill screes on Saddleback round the flanks of Skiddaw by Randel Crag, Carlside, Ullock Pike, to Mire House, and thence across to Brackenthwaite, by Barf, Braithwaite and Grisedale Pike. The outcrop is probably not continuous but may occur in separate folds, nevertheless the graptolite-assemblages point to the existence of this zone over this area as a whole.

The subzone at the top of the Dichograptus Zone has been definitely recognized at the present time in the Hodgson How Quarry at Portinscale, where the working of the quarry has exposed these higher beds. Thirty years ago these higher beds were hardly exposed and the rocks yielded an assemblage more typical of the true Dichograptus Zone, without any *Tetragraptus*. This subzone

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[1] Elles, G. L., 'The Graptolite Fauna of the Skiddaw Slates,' *Quart. Journ. Geol. Soc.*, vol. liv, 1898, p. 516.

[2] Lapworth, C., G. L. Elles, and E. M. R. Wood, 'A Monograph of British Graptolites,' pt. vii, 1908, p. 312, *Palaeont. Soc.*

[3] Elles, G. L., *op. cit.*, 1898, pp. 521-2.

appears also to be exposed at Aiken Gill (Scaw Gill) and to be present at Barf.

The Zone of *Didymograptus extensus* (*sensu lato*) is by far the most extensively developed horizon of the graptolite-bearing Skiddaw Slates. It is found all round the southern and south-western flanks of Skiddaw and Saddleback, and different horizons within it are brought against the Borrowdale Volcanic Series on the south side of the Greta valley. It extends much farther to the east than the Dichograptus Zone has been recorded, having a considerable development in the Mungrisdale area. From Mungrisdale right round this southern region the different subzones may be recognized; thus in the Mungrisdale district the three higher subzones are to be found; Subzones (b) and (c) occurring in their proper relative positions on the crags respectively 150 yds. and 200 yds. W. of Undercrag, and Subzone (c) is seen again on the crag $\frac{1}{2}$-$\frac{3}{4}$ mile S.W. of Mungrisdale church; and Subzone (d) seems to be well developed 250 yds. E. of Hazelhurst, $\frac{3}{4}$ mile south of Mungrisdale. The Subzone (c) of *D. nitidus* (*sensu stricto*) in which *D. protobifidus* makes its appearance is well developed on White Horse Bent, 1750 yds. E. of Scales Tarn outlet, and is well seen again in the Glenderamakin valley.

On the west side of Skiddaw the Subzone (d) of *Isogr. gibberulus* appears to be present on Randel Crag, White Horse Fell and Watches, possibly a once continuous outcrop, and the Subzone (c) of *Didymograptus nitidus* is very generally present, and in places as on White Horse Fell the lower Subzone (b) of *D. deflexus* occurs. On Great Knott the still lower Subzone (a) the upper Tetragraptus Subzone, is present in such a position as to suggest that the beds cannot be far above those belonging to the Dichograptus Zone on Ullock Pike. On the west of the Bassenthwaite valley the assemblage collected from the Barf screes, together with the associations on the same slabs of rock, might lead to the inference that the greater part of the Zone of *D. extensus* is represented, though graptolites representative of the highest subzone are somewhat rare and possibly that subzone is not developed there. At Outerside on the other hand, the fossil-assemblages seem to indicate beds from the middle of the Zone of *D. extensus* up to the Zone of *D. bifidus* so that they are higher as a whole than those at Barf. Still farther west, the *D. extensus* Zone appears to have an extensive development, and an assemblage characteristic of the Subzone (b) of *D. deflexus* has been recorded from near Hudson Place Farm, Loweswater; to the north, the highest subzone seems to be developed on the slopes, S. 4° W. of Lord's Seat summit.

Unlike the Zone of *D. extensus*, the Zone of *D. hirundo* is very restricted in its distribution, which accords well with the evidence derived from the distribution of the highest subzone of the Zone of *D. extensus*. The *D. hirundo* Zone is developed on the west side of the Skiddaw mass in association with the *D. extensus* Subzones at Randel Crag; it is also found on Sandbeds and in the scree on

the left bank of Dead Beck, these last beds yielding an assemblage suggesting proximity to the higher Zone of *Didymograptus bifidus*. The Zone of *Didymograptus bifidus* is still more restricted in its development, for it must be remembered that many of the records of *D. bifidus* are erroneous, the forms being for the most part *D. protobifidus*, or *D. protobifidus-bifidus* transients. The records of *D. nanus* from the Skiddaw Slates are also in most cases erroneous. The Zone of *D. bifidus* is probably just entered at Outerside, and ¾ mile S. of Mungrisdale. It has a really good development at Ellergill, at Thornship Beck, Shap, and at Aik Beck, Pooley.

Comparison with other Areas

Britain and Canada

Following the general usage outside Britain and in order to facilitate comparisons with areas outside the British Isles, the Tremadoc Beds of this country will be included with the Lower Ordovician rocks, and from the point of view of the graptolite faunas, they ally themselves naturally with those rocks. In making comparisons between the graptolite faunas of this and other countries it must be clearly borne in mind that two things will exercise an important control upon the development and succession of the faunas in both time and space; these are (1) the facies of deposit, and (2) structural considerations. One or other or both of these have operated in different areas to bring about apparent anomalies in the succession which are thus apparent only, rather than real.

There is more to be said for the comparison of the faunal succession of the Lower Ordovician of the Lake District with that of Wales than Dixon[1] admits, and less real similarity with the Lévis Shales. It is true that on paper there appears to be considerable similarity, but this is largely due to the presence in Canada of the Dichograptus Zone, which is cut out in both North and South Wales by the unconformity at the base of the Arenig, as it also is in Anglesey; along the Welsh Borderland the horizon of this fauna is probably that of the Stiperstone Quartzite. In Wales therefore, the Arenig succession begins with the Zone of *Didymograptus extensus*; otherwise the faunal assemblages in the two districts agree well.

The Canadian succession at Lévis is more complete, but the whole mode of occurrence of the fossils in the Lévis Shales is so different, that to anyone familiar with both areas the differences seem to outweigh the resemblances. In comparing the faunal assemblages of the two areas it should be remembered: (1) that the Lévis Shales are far more disturbed than many fossil collectors have realized, and are in some places repeated and even completely overturned, due no doubt to their position immediately above the great St. Lawrence Thrust. The general structure as deduced

[1] Dixon, E. E. L., *op. cit.*, 1931, pp. 32-33.

by me from the occurrence of the graptolite-assemblages, had, I found, been anticipated by Logan whose original unpublished sections, now at Ottawa, I was allowed to examine by the courtesy of the Director of the Canadian Geological Survey. Several supposed anomalies in the faunal succession appeared to me to have resulted from the repetition and overfolding. (2) The Lévis Shales are amazingly thin as compared with the Skiddaw Slates especially as regards the beds below the horizon of *D. hirundo*. There are found layers an inch, or even the fraction of an inch, in thickness yielding a fauna found in Britain in beds from 10 to 100 ft. or more in thickness. How thin each shale bed, and yet how marvellously rich its fauna, can perhaps only be appreciated by those who have worked on them. The graptolites are crowded together in masses layer after layer in a manner totally unlike anything seen in the Skiddaw Slates. Naturally under such conditions there is considerable condensation of the faunas, and some inevitable overlapping; but applying the principle of concentration of forms in a definite state of evolution, and noting the first appearances of forms in a more advanced evolutional stage, it is perfectly easy to make out the succession. It is not, I think, possible in this condensed Point Lévis section to subdivide the beds to the extent that has seemed possible in the Skiddaw Slates; but it is possible to note the incoming of *Tetragrapti* above the horizon of concentration of the many-branched graptolites, and these are closely succeeded by the incoming of the horizontal *Didymograpti*. The beds with those faunas represent the whole of the Zones of *Dichograptus* and *Didymograptus extensus*. Another locality, where the true *Phyllograptus typus* occurs (not the forms commonly referred to that species), seems to represent the Zone of *D. hirundo*, and a third locality in Lévis town where the true *D. bifidus* is found in abundance, represents the Zone of *D. bifidus*.

Though the faunal succession as thus determined, agrees in general with what is found in the Skiddaw Slates, the Lévis fauna is in actual fact a very much richer one than that of the English Lake District.

Another element makes for ambiguity, namely, the differences in the terminology; in Scandinavia and Britain for example, the Diplograptid *Glyptograptus dentatus* (Brongniart) is recognized as passing up by a series of transients into *G. teretiusculus* (Hisinger), which may thus quite reasonably be regarded as a late *G. dentatus*, by which name the fossil is known in America. The horizon of this late form must not however be taken to be that upon which *G. dentatus* (*sensu stricto*) typically occurs. This point has been very generally overlooked.

Similarly with the true *Didymograptus bifidus* (Hall); this form seems to be as restricted in horizon in America as it is in Europe, and yet numerous tuning-fork graptolites that are not really Hall's species have been referred to it, and the horizon of the bed in which they occur has been referred to the Zone of *D. bifidus*,

thereby causing a great deal of quite unnecessary confusion. As noted previously, two tuning-fork graptolites make their appearance in the Zone of *D. extensus*. One is a form closely allied to Hall's *D. indentus*, the other differs in having its thecae differently set and more closely spaced; this is *D. protobifidus* sp. nov. (see pp. 98-9). The confusion that has arisen by referring these beds in the middle of the *D. extensus* Zone to the Zone of *D. bifidus* can easily be imagined.

Sweden

In comparing the Skiddaw Slate succession with that found in Vestrogothia,[1] another difficulty confronts us; for here the succession is not only condensed, but the lower part appears to be represented by rocks belonging to another facies of deposit, that of the Ceratopyge Limestone[2]; hence the graptolitic succession as seen at Mossebo must be interpreted as being incomplete. In Törnquist's Zone of *Tetragraptus phyllograptoides*, which rests directly upon the Ceratopyge Limestone, small extensiform *Didymograpti* and reclined *Tetragrapti* are present, and the whole fauna recalls very strongly the subzone at the base of the Zone of *D. extensus* in the Skiddaw Slates. This suggests that the Dichograptus Zone is represented by Ceratopyge Limestone. The evidence for the inclusion of the *T. phyllograptoides* Zone also in the Ceratopyge Limestone is not so convincing and may be questioned.[3] Where the succession is more shaly throughout, as at Flagabro in Scania, the beds between the Dictyonema Zone and the Zone of *T. phyllograptoides* are unfortunately unfossiliferous. Hence the Dichograptus Zone as such, is not represented in Sweden. Törnquist's Zones of *Didymograptus balticus* and *Phyllograptus densus* must together represent the subzones (b) and (c) of the Lake District Zone of *D. extensus* somewhat differently subdivided; *D.balticus* Tullberg is certainly a near ally of *D. v-fractus*, and *Didymograptus vacillans* Tullberg is very near to *D. deflexus*. The Zone of *Phyllograptus densus* contains two transients between *D. nitidus* and *D. hirundo* (*D. suecicus* Tullberg and *D. praenuntius* Törnquist) that indicate its position fairly obviously. His Zone of *Isograptus gibberulus* is rather more embracing than our subzone of that name since owing to condensation it seems also to include the fauna of the Zone of *Didymograptus hirundo*.

Comparison with the Swedish succession thus suggests very strongly that we may have taken too much into the Arenig Beds in Britain and we seem to be faced with two alternatives; either to regard the Arenig strata as beginning with the Zone of *D. extensus*, relegating all lower graptolite-bearing beds to the Tremadoc, or to

[1] Törnquist, S. L., *op. cit.*, 1901.

[2] Moberg, J. C., and C. O. Segerberg, 'Bidrag till Kännedomen om Ceratopygeregionen,' *Medd. Lunds Geol. Falt.*, ser. B, no. 2, 1906, pp. 45-50.

[3] Fearnsides, W. G., 'Review' of Moberg and Segerberg's paper cited above, *Geol.Mag.*, 1907, p. 85. See also
Törnquist, S. L., 'Några Anmärkningar om Indelningar inom Sveriges Kambro-Silur,' *Geol. Fören. Stockh. Förhand.*, bd. xxxv, no. 7, 1913, pp. 407-438.

regard the junction between the Arenig and Tremadoc as occurring in the middle of the Ceratopyge Limestone. The first of these proposals will commend itself to most graptolithologists who have long realized the close relationship of fauna of the upper part of the Dictyonema Shales (the Bryograptus Beds) to that of the Dichograptus Zone.

Australia

In Victoria, perhaps we find the nearest counterpart to our Skiddaw Slate succession as a whole, allowing naturally for certain local differences and additions to the fauna. Here the succession seems to be even more spread out than in the Skiddaw Slates, and thanks to the careful field-work and collecting of T. S. Hall[1] and W. J. Harris[2] the Zone of *Didymograptus extensus* has already shown itself to be divisible into many subzones.[3]

The Lancefieldian represents without doubt the Dichograptus Zone, *i.e.* the horizon of the many-branched graptolites, including the lower Tetragraptus Subzone ; the Bendigonian and Castlemainian, the Zone of *Didymograptus extensus*; and the Darriwilian, the Zone of *Didymograptus hirundo* together with the Zones of *Didymograptus bifidus* and *D. murchisoni*.

Explanations of Text-figures 1—13

All figures represent a magnification of 3 times unless otherwise stated. In all cases the registration numbers of the specimens are cited. The specimens bearing the numbers 51989 to 51993 were collected by members of the Geological Survey staff and are in the collection of the Geological Survey in London.

The author is greatly indebted to Dr. O. M. B. Bulman for the clear drawings of graptolites in illustration of this paper.

Fig. 1. *Didymograptus protobifidus* sp. nov., holotype. Skiddaw Slates, probably high up in Zone of *D. extensus* ; Outerside, W.S.W. of Keswick, Cumberland. Specimen figured in ' Monograph of British Graptolites,' 1901, pl. iv, fig. 5d as *Didymograptus nanus* Lapworth. British Museum (Nat. Hist.) P. 1856.

Fig. 2. *Didymograptus protobifidus* sp. nov., compressed form with divergent stipes. Skiddaw Slates, the same horizon (probably) and locality as Fig. 1. Sedgwick Museum, 221.

Fig. 3. *Didymograptus protobifidus* sp. nov. Skiddaw Slates, Zone of *D. extensus*, Subzone (d) of *Isograptus gibberulus* ; scree, 250 yds. E. of Hazelhurst, ¾ mile S. of Mungrisdale, Cumberland. 51989.

[1] Hall, T. S., ' Victorian Graptolites, pt. II. The Graptolites of the Lancefield Beds,' *Proc. Roy. Soc. Victoria*, vol. xi, pt. 2, 1899, pp. 164-178, pls. xvii-xix ; ' Recent Advances in our Knowledge of Victorian Graptolites,' *Rep. Austral. Assoc. Adv. Sci.*, vol. xii for 1909 (Brisbane), 1910, pp. 318-320.

[2] Harris, W. J., ' The Palaeontological Sequence of the Lower Ordovician Rocks in the Castlemaine District,' *Proc. Roy. Soc. Victoria*, new series, vol. xxix, pt. 1, 1916, pp. 50-74.

[3] David, T. W. Edgeworth, ' Explanatory Notes to accompany a new Geological Map of the Commonwealth of Australia,' 1932, table facing p. 41.

Fig. 4. Late transient of *Didymograptus protobifidus-bifidus* = early mutation of *D. bifidus* (Hall). Skiddaw Slates (upper part), base of Zone of *D. bifidus*; Thornship Beck, Shap, Westmorland. Sedgwick Museum, 209.

Fig. 5. *Didymograptus bifidus* (Hall). Skiddaw Slates (upper part), Zone of *D. bifidus*; Ellergill, S.W. of Kirkby Stephen, Westmorland. Sedgwick Museum, 191.

Fig. 6. *Didymograptus extensus* (Hall). Skiddaw Slates, probably top of *D. extensus* Zone; E. margin of scree, S. side of Randel Crag, 820 yds. W. 18° N. of Skiddaw Man, Cumberland. 51990.

Fig. 7. *Didymograptus extensus* (Hall), × 4 approx. Skiddaw Slates, Zone of *D. hirundo* (probably near base); stream bend, 30 yds. N. of Abbey Gate, 2 miles N.N.E. of Mosser church, Cumberland. 51991.

Fig. 8. *Didymograptus nitidus* (Hall). Skiddaw Slates, east of Longside, S.W. of Skiddaw, Cumberland. Specimen figured in 'Monograph of British Graptolites,' 1901, pl. i, fig. 2a. Sedgwick Museum.

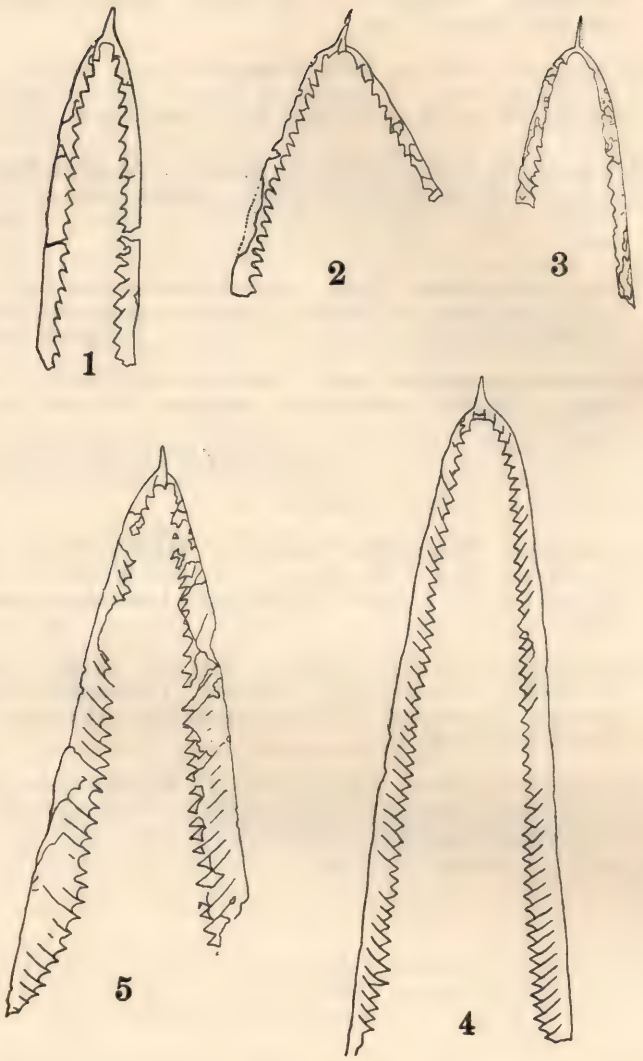
Fig. 9. *Didymograptus patulus* (Hall). Skiddaw Slates, Burn Tod Gill, north of Skiddaw, Cumberland. Sedgwick Museum, 265.

Fig. 10. *Didymograptus suecicus* Tullberg. Skiddaw Slates, probably *D. extensus* Zone, Subzone (d) of *Isograptus gibberulus*; Randel Crag, Skiddaw, Cumberland. Sedgwick Museum, 29.

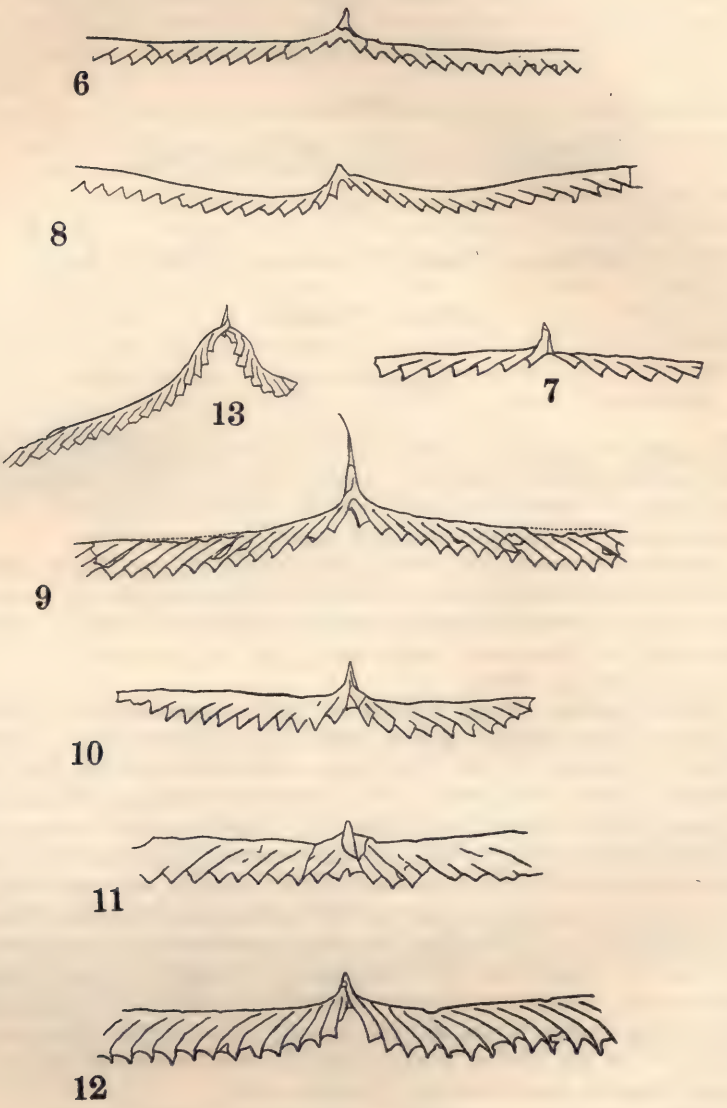
Fig. 11. *Didymograptus praenuntius* Törnquist. Skiddaw Slates, high in *D. extensus* Zone; old quarry, N.W. foot of Murton Fell and 500 yds. S. 17° E. of South Felldyke Farm, Lamplugh, Cumberland. 51992.

Fig. 12. *Didymograptus hirundo* Salter. Skiddaw Slates, Zone of *D. hirundo*; Randel Crag, Skiddaw, Cumberland. Specimen figured in 'Monograph of British Graptolites,' 1901, pl. i, fig. 5b. Sedgwick Museum, 28.

Fig. 13. *Didymograptus deflexus* Elles and Wood. Skiddaw Slates, Zone of *D. extensus*, Subzone (b) of *D. deflexus*; crag, 150 yds. W. of Undercrag, Mungrisdale, Cumberland. 51993.



FIGS. 1-5.—*Tuning-fork* Didymograpti *from the Skiddaw Slates.*



FIGS. 6-13.—*Extensiform* Didymograpti *from the Skiddaw Slates.*

VI.—THE FAUNA OF THE PALAEOZOIC ROCKS OF THE LITTLE MISSENDEN BORING

BY

S. H. STRAW, M.Sc., F.G.S.

WITH A

REPORT ON THE FISH REMAINS

BY

SIR ARTHUR SMITH WOODWARD, LL.D., F.R.S.

Plates IX and X.

INTRODUCTION

THE deep boring made near Little Missenden (Bucks.) in 1913, after passing through Mesozoic rocks, entered the Palaeozoic floor at a depth of approximately 1200 ft. below the surface. It was discontinued after piercing the Palaeozoic rocks for 64 ft.

Details of the exact situation of the boring, its position in relation to other deep borings in south-eastern England in which Palaeozoic rocks have been reached, with notes on the Mesozoic rocks, a detailed section of the Palaeozoic rocks and a list of the fossils obtained, were published in 1916.[1]

The Palaeozoic rocks consist of grey, micaceous, fine-grained sandstones and sandy shales with thin fossiliferous limestone bands. In general aspect the fauna resembles that of the Upper Ludlow rocks of Shropshire with which the Missenden beds were correlated in the original account. At that time the Ludlow Bone Bed was generally regarded as the topmost layer of the Upper Ludlow, and the correlation was made actually with the Ludlow Bone Bed and the upper part of the underlying Whitcliff Flags.

In 1923, Dr. L. D. Stamp, having transferred the Ludlow Bone Bed to the base of the overlying Temeside Group (Lower Downtonian), preferred a Lower Downtonian age for the Missenden beds as the fauna "was almost exactly that of the *Platyschisma* Shales."[2] To the list of fossils given by the Geological Survey he added *Thelodus parvidens* and *Thelodus spp.*

These previously-suggested correlations were based chiefly on the supposed identity of most of the Missenden species with species from Shropshire. This is evident from the list of fossils given in each case. A comparison of the Missenden material with specimens from Shropshire reveals, however, that the striking

[1] 'Summary of Progress' for 1915 (*Mem. Geol. Surv.*), 1916, pp. 43-46.
[2] *Geol. Mag.*, 1923, p. 403.

resemblance of the faunas is due rather to similarity of facies than to identity of species. The majority of the Missenden species are more closely allied to species occurring in extra-British areas than to those of Shropshire. Certain of them are found in Shropshire, some occur in erratics on the North German Plain, others are closely allied to, if not identical with, species known only from eastern North America, whilst at least one form shows distinctly austral affinities.

The faunal assemblage does not appear to have been recognized, as a whole, elsewhere. The problems of its age and correlation thus acquire an enhanced interest and importance. It was realized at an early stage of the investigation that the Fish-remains were likely to play a leading part in the solution of these problems. They were accordingly submitted to Sir Arthur Smith Woodward, who kindly undertook to report on them. The writer is indebted also to Professor O. T. Jones, whose collection of fossils from Arisaig, Nova Scotia, has supplied valuable clues to the correlation of the Missenden fauna, and to Dr. F. L. Kitchin for free use of the Geological Survey material and for detailed information of the exact position of the specimens in the boring.

In the following descriptions, specimens are referred to individually by their numbers in the Geological Survey registers.

Description of the Fauna

ANNELIDA

Cornulites serpularius Schlotheim

Plate IX, fig. 1.

1820. *Cornulites serpularius* E. F. Schlotheim, 'Die Petrefactenkunde,' p. 378, Taf. xxix, fig. 7.

The Missenden form of this species is small and rather irregularly curved. The largest specimen [51873] measures 11 mm. in length but is incomplete apically. The annulations vary in width. They do not show the longitudinal striations described by J. de C. Sowerby[1] and usually regarded as characteristic of the genus, but this is probably due to poor preservation.

Occurrence.—Specimens have been found at the following depths in the boring : 1216 ft. [51857] ; 1219 ft. [Pl. 4783] ; 1233 ft. [51873] ; 1234 ft. [Pl. 4798].

Worm borings are very abundant in the shales at various levels in the core.

CRINOIDEA

Narrow crinoid stems up to three inches in length occur at various levels in the core (*e.g.* Pl. 4853). They appear to belong to more than one type since some are smooth and others have the outsides of the columnals covered with small tubercles [Pl. 4839]. Isolated columnals abound on some of the bedding planes.

[1] In Murchison's 'Silurian System,' p. 627.

BRYOZOA

Rhopalonaria sp.

Plate IX, fig. 2.

Zoarium growing on and partly embedded in the shells of brachiopods. Cells fusiform, connected by slender stolons and arranged in a pinnate manner, the lateral branches making an angle of 55°—70° with the mid-rib. Where more than one zoarium has occupied the same shell a confused network of cells results. (See the right hand side of the figured specimen).

Occurrence.—At 1224 ft. [51858] and 1225 ft. 6 ins. [Pl. 4789A].

Remarks.—The specimens occur as siliceous internal casts of the base of the zoarium from which the shell in which they were originally embedded has been dissolved away. I have not been able to identify the Missenden form with any of the species described by Ulrich and Bassler in their monograph of the Ctenostomatous Bryozoa.[1] It shows some resemblance to their *R. robusta*, but the state of preservation is too poor for a confident determination of the species.

BRACHIOPODA

Lingula missendenensis sp. nov.

Plate IX, figs. 3 a, b.

Holotype.—No. 51859.

Description of Holotype.—Shell small, relatively broad, evenly convex, parallel-sided; posterior end short; anterior end bluntly rounded; posterior half of the shell-substance folded into wavy concentric wrinkles which anteriorly pass rather abruptly into a fine reticulation due to the crossing of the wrinkles by oblique raised lines.

Dimensions.—The holotype is incomplete, but the complete shell would measure about 6 mm. in length and 5.5 mm. in width.

Occurrence.—Fragments of this species are fairly common from 1200 ft. to 1229 ft., but are rare below the latter level.

Remarks.—In form and in the possession of wavy, concentric wrinkles, this species resembles *L. scobina* Williams,[2] from the Pembroke formation of Washington County, Maine, but it is much smaller and the wrinkling is relatively coarser. A similar shell-structure is seen in *L. striata* J. de C. Sow., the type of which comes from the Lower Ludlow of Aymestrey.

[1] *Smithsonian Misc. Coll.*, vol. 45, p. 256 *et seq.*
[2] *Proc. U.S. Nat. Mus.*, vol. 45, 1913, p. 339, pl. 30, fig. 18.

Lingula zigzag sp. nov.

Plate IX, figs. 4 a, b.

Holotype.—No. 51860A.

Description of Holotype.—Shell small, twice as long as broad, with a narrow flattened longitudinal median area and sloping sides; anterior end bluntly rounded; surface with concentric growth-lines and, in addition, an ornament of fine zig-zag raised lines.

Dimensions.—The posterior end of the holotype is broken off, but the complete shell would have a length of about 4 mm. and a width of 2 mm.

Occurrence.—Fragments are common between 1245 ft. 6 ins. and 1246 ft.

Remarks.—The ornament is only preserved anteriorly: it is possible that the shell was not similarly ornamented all over.

This species resembles *L. punctata* Hall,[1] of the Lower Helderberg, both in type of ornamentation and in the presence of a flattened median area, but it is considerably smaller than the specimens figured by Hall and the shell is narrower in proportion to the width.

Orbiculoidea crucifera sp. nov.

Plate IX, fig. 5.

Holotype.—51861A and counterpart 51860B.

Description of Holotype.—A ventral valve, broadly elliptical in shape, slightly convex, with central apex; ornamented with well-marked cencentric ridges of unequal height and width, crossed by exceedingly fine radial striae. Inner surface smooth, with a cruciform pedicle elevation extending posteriorly for slightly less than half the distance from the apex to the margin and ending in a minute pedicle foramen.

Dimensions of Holotype.—Length 3 mm.; width 2.8 mm. (approx.).

Occurrence.—Found at 1245 ft.

Remarks.—The most distinctive features of this species are the shape of the pedicle elevation and the relative coarseness of the concentric ridges. Scattered fragments from the same level in the core show that the species attained a larger size than that of the holotype. The latter was chosen as being the only specimen to show with any degree of completeness the characters of the interior of the shell.

[1] *Palaeontology of New York*, vol. iv, p. 10, pl. i, fig. 6; and vol. viii, pl. i, fig. 26.

Orbiculoidea sp.

Plate IX, fig. 6.

A specimen of an incomplete and decorticated dorsal valve [51862] nearly half an inch in length from between 1257 ft. and 1263 ft. shows some resemblance in form to *O. rugata* (J. de C. Sow.), but as neither the exterior nor the interior of the shell is present for examination it cannot be identified with certainty.

Pholidops antiqua (Schlotheim)

Plate IX, fig. 7.

1885. *Pholidops antiqua* (Schlotheim), M. Werworn, *Zeitschr. d. deutsch. geol. Gesellsch.*, Bd. xxxvii, pp. 173-176 and text-figures 1-7.

1909. *Pholidops antiqua* J. C. Moberg and K. A. Grönwall, *Lunds Univ. Årsskrift*, N.F., Afd. 2, Bd. 5, No. 1, p. 30, pl. ii, figs. 8 and 9.

Shell oval in outline, posterior end narrower and more depressed than the anterior; a narrow, flat, marginal rim surrounding the inner surface of the shell; muscle-areas consisting of a relatively large bilobed callosity in the middle of the shell and a pair of smaller scars anteriorly.

Dimensions.—Length 2.5 mm.; width 1.8 mm.

Occurrence.—A single specimen has been observed at 1214 ft. and several specimens (including 51863) at 1245 ft.

Remarks.—This species is slightly larger and more elongate than the form of *P. implicata* (J. de C. Sow.) occurring in the Upper Ludlow. Only one specimen shows the internal characters clearly, and in this the central muscle-area is relatively much larger than in the corresponding valve of *P. implicata*. The Missenden form approximates more closely to *P. antiqua* (Schloth.) of the Baltic Provinces than to the British form, and shows also considerable resemblance to *P. acadiensis* (Hall) from the Stonehouse Beds of Arisaig as figured by McLearn.[1]

Dalmanella missendenensis sp. nov.

Plate IX, figs. 8, 9, 10.

Syntypes.—A dorsal valve [51865] and a ventral valve [51866].

Description.—Shell subcircular in outline, beaks not prominent; both valves moderately convex, the ventral slightly more so than the dorsal; dorsal valve becoming flatter anteriorly and developing a shallow, gradually broadening median depression; hinge-line slightly more than half the width of the shell; radial ribs rather coarse and showing two stages of bifurcation in their course from the

[1] McLearn, F. H., 'Palaeontology of the Silurian Rocks of Arisaig, Nova Scotia,' *Geol. Surv. Canada*, Memoir 137, 1924, pl. x, fig. 10.

umbo to the anterior margin. In the ventral valve the dental plates diverge from the umbo at an angle of 65°; from their anterior ends inwardly curving ridges extend along the floor of the valve and bound the sides of the sub-cordate muscle-area. In the dorsal valve the simple knob-like cardinal process supported by a median ridge extending forwards for about one-sixth the length of the valve; crural bases short, stout, and slightly curved outwards, diverging at an angle of about 40°; dental sockets diverging at an angle of 120°; the halves of the faintly-marked quadrangular adductor area separated by a gentle elevation.

Dimensions.—Length 8 mm.; width 8.5. mm.

Occurrence.—Fairly common between 1200 ft. and 1229 ft.; rare below that level. The syntypes are both from 1224 ft.

Remarks.—This species has close affinities with *Dalmanella lunata* (J. de C. Sow.), which it resembles closely in the internal characters of the ventral valve. It differs, however, in the following features: (i) the ribbing is relatively coarser; (ii) in the dorsal valve the muscle-area is more quadragonal, the crura diverge at a greater angle and their bases are not continued as ridges bounding the muscle-area.

Chonetes novascoticus Hall, var. *missendenensis* var. nov.

Plate IX, fig. 11.

Holotype of variety.—The ventral valve numbered 51867.

Shell nearly twice as wide as long; hinge-line less than the greatest width, which occurs about half-way between the anterior and posterior margins; lateral margins evenly rounded. Ventral valve moderately convex; cardinal margin with at least four pairs of small outwardly directed spines; radial striae 27 per 10 mm. on anterior border; internal median septum short. Dorsal valve flat; more strongly pustulated internally than the ventral valve.

Dimensions.—Length 13 mm.; width 23 mm.

Occurrence.—Abundant in the upper 29 ft. of the boring; less common in the lower 35 ft. The holotype occurred at a depth of 1214 ft.

Remarks.—This fossil is very similar to the large form of *C. novascoticus* Hall described and figured by McLearn[1] from the uppermost zone of the Stonehouse formation at Arisaig, Nova Scotia. The radial surface striae are less numerous than in typical specimens of that form, but more numerous than in *C. novascoticus*, mut. *crassistriatus* McLearn from probably the same horizon in the Stonehouse. It also closely resembles *C. bastini* Williams from the Pembroke formation of Eastport, Maine. From *C. striatellus* it differs in being larger and flatter, in having less flexuous striae and in the fact that the hinge-line in all the specimens seen is not the greatest width of the shell. The latter feature is, however

[1] *Op. cit.*, p. 66, and pl. v, fig. 35.

variable in *C. striatellus*, for whilst in the great majority of specimens the hinge-line forms the greatest width of the shell, in others we have an approach to the condition seen in the Missenden variety; but considering all the characters of the shells, there can be little doubt that the Missenden specimens are closer to the North American form than to that of the Shropshire Upper Ludlow. At one level (1204 ft.) in the boring occur specimens showing a broad, shallow median depression in the ventral valve. Hall, in his original description[1] of *C. novascoticus* stated that the ventral valve often showed "a flattened or slightly concave space down the middle of the shell." It has not been considered necessary, therefore, to create a fresh name for these. Hall further remarked that "a stronger or more elevated stria often marks the median line from beak to base of the ventral valve." This feature is only rarely observed in Missenden specimens [Pl. 4771]. According to McLearn it is not always present in the Stonehouse forms. It would not appear thus to be an essential character of the species.

Camarotoechia glomerosa McLearn

Plate IX, figs. 12, 13.

1924. *Camarotoechia glomerosa* McLearn, *op. cit.*, p. 71, pl. v, figs. 15-19.

Outline subcircular; both valves strongly convex; median fold and sinus developed only in later stages of growth and then not prominently; from twenty to twenty-four rounded ribs on each valve. In the dorsal valve the fold with four ribs which expand anteriorly; ten ribs on each side of the fold; internally, the dorsal median septum extending about one-third the length of the valve and supporting a small narrow cruralium; the crural bases diverging at an angle of 110°. In the ventral valve the sinus with three to four ribs; from eight to ten ribs on either side; dental plates well developed, sub-parallel.

Dimensions.—Length 11 mm.; width 11.5 mm.

Occurrence.—The most complete specimens occur at 1223 ft. [51868], but fragments are common from 1200 ft. to 1229 ft. and less common below the latter level.

Remarks.—This form agrees very closely with that described and figured by McLearn as *C. glomerosa* and, in all probability, is identical with that species. According to the latter author, "Some forms of this variable species suggest *Wilsonia wilsoni* (Sowerby)"[2] In this connection it may be noted that the previous list of Missenden fossils given by the Geological Survey includes *? Wilsonia.* The specimens upon which this doubtful identification appear to have been based are fragmentary and not well preserved, but their ribs are too strongly convex for *Wilsonia.* They are, more probably, incomplete large specimens of *C. glomerosa.*

[1] *Can. Nat. Geol.*, vol. 5, 1860, p. 144.
[2] *Op. cit.*, p. 71.

This species differs from the well-known *C. nucula* of the Upper Ludlow, with which the typical specimens were originally identified, in the more nearly circular outline, more rounded ribbing and larger number of ribs on the sides of the shell.

LAMELLIBRANCHIATA

The material for the study of the Lamellibranchiata is, unfortunately, not very satisfactory. Of the ten species present in the fauna seven are represented by single specimens of one valve only. In no case are the hinge characters visible and, owing to the hardness of the rock, attempts to expose the hinges have not been successful. In these circumstances, the descriptions are necessarily incomplete and the identification only approximate.

? Ctenodonta hercynica Beushausen

Plate IX, fig. 14.

1884. *Ctenodonta hercynica* L. Beushausen, ' Beitr. z. Kenntn. d. Oberharzer Spirifensandsteins,' *Abhandl. z. geol. Spezialkarte v. Preuss.*, Bd. vi, Heft 1.

1913. *Ctenodonta hercynica* Beush., W. Kegel, ' Der Taunusquarzit von Katzenelnbogen,' *Abh. d. k. preuss. geol. Landesanstalt*, N.F., 76, p. 77, Taf. 4, fig. 6.

Shell elongate, twice as long as high; umbo situated about one-third the distance from the anterior end; anterior end evenly rounded; cardinal line posterior to umbo, straight and gently inclined posteriorly; posterior end narrowly rounded; ventral margin gently convex, slightly impressed behind the middle; anterior adductor impression bounded posteriorly by a low upwardly-broadening ridge; shell-substance moderately thick, with fine concentric surface striations; hinge not known.

Dimensions of figured specimen [51861B].—Length 20 mm.; height 10 mm.

Occurrence.—The specimens of this species are restricted to the 1245 ft. 6 ins.—1246 ft. level, where they are common and are associated with *Plectonotus trilobatus* (J. de C. Sow.), *Hormotoma missendenensis* sp. nov., and fragmentary fish-remains.

Remarks.—In form, in the possession of a thick concentrically striated shell and of a low upwardly-broadening ridge behind the anterior adductor, this species resembles the form of *Palaeoneilo attenuata* (Hall) described by McLearn[1] from the Stonehouse Beds of Arisaig, but it is not so sharply attenuated posteriorly and the broad post-median sulcus which is so characteristic a feature of the latter species is scarcely developed in the Missenden specimens. The latter may be more closely compared with the Lower Devonian *Ctenodonta hercynica* Beushausen, which they resemble in form and size and in the internal features of the shell.

[1] McLearn, *op. cit.*, p. 98 and pl. xii, fig. 10.

Unfortunately, it has not been possible to determine the hinge characters of the Missenden species, so that its generic determination remains uncertain.

? Nucula sp.

Plate IX, fig. 15.

Shell thin, inequilateral, subtriangular in outline; umbo rather sharp, situated about quarter the distance from the posterior end; surface evenly convex, smooth; posterior end short, bluntly rounded; anterior end produced and more sharply rounded; hinge not known.

Dimensions.—Length 23 mm.; height 16 mm.

Occurrence.—At 1233 ft. [51869].

Remarks.—There is only one specimen, an internal cast of a right valve. It was originally identified as *Orthonota amygdalina* (J. de C. Sow.), but its form is quite different from that of the latter species, being shorter and more evenly convex. In these respects, it presents the appearance of *Nucula* and has been described as such, but in the absence of knowledge of the hinge characters the generic determination remains uncertain.

Palaeoneilo attenuata (Hall)

Plate IX, fig. 16.

1860. *Tellinomya attenuata* Hall, *Can. Nat. and Geol.*, vol. v, p. 151, fig. 11.

1885. *Palaeoneilo attenuata* Hall, *Palaeontology of New York*, vol. v, pt. 1, p. 346 and plate 50, figs. 34-39.

1924. *Palaeoneilo attenuata* McLearn, *Can. Geol. Surv.*, Mem. 137, pp. 98-99, pl. xii, figs. 8-10.

Shell elongate, umbo situated one third the distance from the anterior end; anterior end rounded; greatest height of shell beneath the beak; posterior portion produced and tapering to a more narrowly rounded end than the anterior; a broad, shallow, ventrally-widening hollow running obliquely backwards across the valve from the posterior side of the umbo to the post-median portion of the ventral margin; outer surface with fine concentric growth-lines.

Dimensions.—Length 19 mm.; height 10 mm.

Occurrence.—At 1245 ft. [51870].

Remarks.—One specimen only, a left valve, of this species has been recognized. Its elongated form and the well developed post-median sinus are its most characteristic features, and in these the Missenden form shows a close correspondence with the North American species to which it is referred.

Nuculites cf. *antiqua* (J. de C. Sow.)

Plate IX, fig. 17.

1839. *Cucullaea antiqua* J. de C. Sowerby, in Murchison's 'Silurian System,' p. 602, pl. iii, fig. 1b.
1854. *Cucullella antiqua* F. M'Coy, 'British Palaeozoic Fossils,' p. 284.

Shell small, broadly ovate, evenly convex; anterior end broadly and evenly rounded; ventral margin convex; posterior end more sharply rounded; cardinal line inclined backwards towards the postero-ventral angle; a long slender forwardly-curving clavicle extending for two-thirds of the way from the beak to the ventral margin.

Dimensions.—Length 10 mm.; height 7.5 mm.

Occurrence.—At 1214 ft. [51871A].

Remarks.—There is only one good specimen, an internal cast of a right valve. In size and shape it closely approaches *Nuculites antiqua* (J. de C. Sow.), but the posterior adductor is not impressed and the clavicle is longer and more slender.

Nuculites cf. *coarctata* (Phillips)

Plate IX, fig. 18.

1846. *Nucula coarctata* J. Phillips, *Mem. Geol. Surv.*, vol. ii, pt. 1, p. 366, pl. xxii, figs. 1-4.
1854. *Cucullella coarctata* M'Coy, 'British Palaeozoic Fossils,' p. 284.

Shell small, transversely ovate; beaks small, anterior, situated about one-sixth the distance between the anterior and posterior ends; anterior end short and bluntly rounded; posterior end more sharply contracted; a well-marked post-umbonal carina; a shallow, gradually widening depression extending from behind the beak to the postero-ventral border; surface ornamented by concentric striae; shell-substance thick.

Dimensions.—Length 12 mm.; height 8 mm.

Occurrence.—At an indefinite level between 1200 ft. and 1220 ft. [51872A].

Remarks.—This species is represented by a single specimen, a right valve, from which the shell has been, in part, removed. It resembles *Nuculites coarctata* (Phillips) in size and in the possession of a carina, but differs in having a shorter anterior end and in the absence of fine radial striae in addition to the concentric ones. Phillips's figures show some variation of form. The Missenden specimen is closest to his fig. 1, but has a shorter anterior end. It is probably a new species, but the inadequacy of the material prohibits the possibility of a satisfactory diagnosis.

Nuculites corrugata Williams

Plate IX, fig. 19.

1913. *Nuculites corrugata* Williams, *Proc. U.S. Nat. Mus.*, vol. 45, p. 347 and pl. 31, fig. 11.

Shell thin, strongly convex, inequilateral; umbo situated about one-quarter the distance between the anterior and posterior ends; anterior end rounded; ventral margin convex, gently impressed posteriorly; posterior end obliquely truncated; a broad, shallow depression running obliquely across the shell from behind the umbo to the impression of the ventral margin; a strong clavicle extending internally from just in front of the umbo to more than half-way towards the ventral margin; shell with strong growth-lines and with a tendency for the development of concentric corrugations.

Dimensions.—Length 30 mm.; height 20 mm.

Occurrence.—At 1233 ft. [51873].

Remarks.—The only specimen is an internal cast of a left valve with the umbo truncated by a calcite vein. In form and in size of the clavicle this shell resembles *Nuculites concentricus*, var. *subovatus* (Hall) as figured by McLearn,[1] but it is even more closely similar to *Nuculites corrugata* Williams, particularly the rather short variety of the species.

Modiolopsis cf. *complanata* (J. de C. Sowerby)

Plate IX, fig. 20.

1839. *Pullastra complanata* J. de C. Sowerby, in Murchison's 'Silurian System,' p. 609, pl. v, fig. 7.

Shell smooth, moderately elongate, slightly expanded posteriorly; umbo sub-terminal; anterior end small and well rounded; posterior end obliquely truncated; postero-ventral angle sharply rounded; umbonal ridge dying out just before reaching the postero-ventral angle; lateral face flattened; post-umbonal slope very gently concave immediately behind the umbo, but becoming convex towards the postero-ventral angle.

Dimensions.—Length 17 mm.; height 10.5 mm.

Occurrence.—At an indefinite level between 1257 ft. and 1263 ft. [Pl. 4836, 51874].

Remarks.—Of this species the collection contains only the internal cast and external mould of a left valve. This specimen is smaller than typical representatives of the species from the Lower Downtonian of Shropshire, but the general proportions are the same. It may represent an immature individual.

[1] *Op. cit.*, pl. xii, figs. 13 and 16.

? Goniophora sp.

Plate IX, fig. 21.

Shell small, markedly convex below the beak; umbo subterminal; a sharp, slightly sinuous post-umbonal ridge extends to the postero-ventral angle; anterior end short, well rounded; ventral margin gently convex; posterior margin oblique; post-umbonal slope narrow; hinge-line short; anterior adductor only slightly impressed; posterior adductor more strongly impressed and situated almost at the foot of the post-umbonal slope; surface smooth or with concentric growth-lines.

Dimensions (*approximate*).—Length 15 mm.; height 10 mm.

Occurrence.—One specimen only at an indefinite level between 1200 ft. and 1220 ft. [51875].

Remarks.—In the original account this specimen was identified as *Orthonota decipiens* (M'Coy). The anterior end is, however, too tumid for this species. Further, the shell is not sufficiently elongate for *Orthonota*. In the latter genus, too, the post-umbonal ridge is straight except in the vicinity of the umbo. On the whole, the characters presented by this form suggest *Goniophora* except for the narrow post-umbonal slope and short hinge. There is some uncertainty, however, as to the extent of the development of these features. The posterior margin is broken and incomplete. Possibly, therefore, the post-umbonal slope was broader and more wing-like than it appears in the specimen. If so, the resemblance to *Goniophora* would be more complete.

Anodontopsis sp.

Plate IX, fig. 22.

Shell sub-orbicular, moderately convex; umbones narrow and slightly anterior; a strong posterior lateral tooth or ridge just below the hinge-line; shell concentrically wrinkled, the wrinkles becoming stronger towards the margin.

Dimensions.—Length 9 mm.; height 8 mm.

Occurrence.—At an indefinite level between 1200 ft. and 1220 ft. [51872B].

Remarks.—There is only one specimen, an internal cast of a right valve. It resembles *Anodontopsis bulla* M'Coy more closely than any other species of the genus, but is less nearly circular in outline and possesses only a single lateral tooth in the right valve instead of a double one.

Lamellibranch indet.

A fragment of a flat valve of a coarsely, radiately ribbed lamellibranch, possibly *Palaeopecten*, occurs at an indefinite level between 1200 ft. and 1220 ft. [Pl. 4853], but is too incomplete for a closer identification.

GASTROPODA

Hormotoma cf. *articulata* (J. de C. Sowerby)

Plate IX, figs. 23, 24.

1839. *Pleurotoma articulata* J. de C. Sowerby, in Murchison's 'Silurian System,' p. 612, pl. v, fig. 25.
1899. *Hormotoma articulata* J. Donald, *Quart. Journ. Geol. Soc.*, vol. lv, p. 268, pl. xxii, figs. 7, 8.

Shell turreted, with at least seven strongly convex whorls; apical angle 27°; slit-band near the middle of the whorl, slightly depressed and delimited on each side by a raised thread.

Occurrence.—Common at 1214 ft., less common at lower levels.

Remarks.—This shell resembles *H. articulata* (J. de C. Sow.) in all observable features except size, in which it differs in being smaller than the typical examples of the species. This may be due, of course, to the immaturity of the Missenden specimens. From *H. moniliformis* Lindstr.,[1] a very similar form, it appears to differ only in having a smaller apical angle.

Hormotoma missendenensis sp. nov.

Plate IX, fig. 25.

Holotype.—51878 from 1245 ft. 6 ins.—1246 ft. The holotype is an immature shell, but was chosen because it showed the position of the slit-band and the direction of the growth-lines.

Other material.—Specimens numbered 51877, Pl. 4832, Pl. 4826, and Pl. 4794. All from 1245 ft. 6 ins.—1246 ft.

Description of Holotype.—Shell turreted, apical angle 22°; whorls almost as high as wide, with flattened sides; smooth except for faint transverse growth-lines which are deflected backwards from the sutures to the slit-band; slit-band situated in the middle of the whorl, smooth and flat, not depressed and not delimited by raised lines.

Occurrence.—Abundant at 1245 ft. and 1245 ft. 6 ins.; rather rare at higher levels.

Remarks.—The form of the shell of this species presents a striking resemblance to that of *H. cingulata* (Hisinger). It does not, however, attain the large size shown by typical specimens of that species; but the most important difference lies in the position of the slit-band. In *H. cingulata* this is situated low down in the whorl, whereas in *H. missendenensis* it runs along the middle.

[1] Lindström, G., 'On the Silurian Gastropoda and Pteropoda of Gotland,' *K. Svensk. Vetensk. Akad. Handl.*, vol. xix, No. 6, 1884, p. 128, pl. xii, figs. 5-6.

Plectonotus trilobatus (J. de C. Sowerby)

Plate IX, figs. 26, 27.

1839. *Bellerophon trilobatus* J. de C. Sowerby, in Murchison's 'Silurian System,' p. 604, pl. iii, fig. 16.
1924. *Plectonotus trilobatus* McLearn, *op. cit.*, p. 140, pl. xx, figs. 18, 30, 31, 32.

Shell coiled in a plane spiral and divided into three lobes by longitudinal grooves; lobes rounded and gradually increasing in size from the apex to the aperture; median lobe somewhat broader than each of the side lobes, becoming increasingly more so towards the aperture; shell smooth except for fine growth-lines which swing backwards towards the slit-band; slit-band broad [51861], with very fine transverse growth-lines. Umbilicus small and deep.

Occurrence.—Abundant at 1245 ft. 6 ins.—1246 ft., where it forms a band in association with *? Ctenodonta hercynica* Beushausen, *Hormotoma missendenensis* sp. nov., and fragmentary fish-remains. It does not occur outside this band.

Remarks.—In size of shell, width and depth of the umbilicus and relative breadth of the lobes, the Missenden specimens agree closely with the original description and figures given by Sowerby in 'The Silurian System.'

Tentaculites annulatus Schlotheim

Plate X, figs. 1a, b, 2.

1820. *Tentaculites annulatus* Schlotheim, 'Die Petrefaktenkunde,' p. 377, Taf. 29, fig. 8a.
1909. *Tentaculites annulatus* J. C. Moberg and K. A. Grönwall, *op. cit.*, p. 46, Taf. ii, fig. 1.

Shell elongate-conical attaining, in the mature portion, a diameter of 3 mm.; ornamented with annulations and fine annular growth-lines; annulations regularly spaced throughout, increasing in height and width with increase in diameter of the shell; interspaces slightly wider than the annulations; annulations 10 in a length of 2.5 mm. at 0.6 mm. diam., and 10 in a length of 8.5 mm. at 3 mm. diameter.

Occurrence.—Not common at any level, but extending practically throughout the core.

Remarks.—The regular spacing of the annulations distinguishes this species from *T. ornatus* J. de C. Sow. and *T. tenuis* J. de C. Sow., and also from *T. irregularis* de Koninck. It appears, rather, to belong to *T. annulatus* Schlotheim, but the original figures of this species are so unsatisfactory that the identification is uncertain. It agrees closely, however, with the form figured by Moberg and Grönwall as *T. annulatus* Schlotheim. It resembles also *T. crotalinus*

Salter from the Lower Devonian rocks of South Africa and South America.

In the specimens from the upper half of the boring the annulations can be traced back to the apex, but in those from the lower beds the shell is smooth for at least the first 2 mm. from the tip.

CEPHALOPODA

Kionoceras angulatum (Wahlenberg)

Plate IX, figs. 28a, b.

1821. *Orthoceras angulatum* Wahlenberg, *Nova Acta Reg. Soc. Sci. Acad. Upsala*, vol. viii, p. 90.

1885. *Orthoceras damesi* F. Roemer, 'Lethaea Erratica,' etc., *Palaeont. Abhandl.*, Bd. ii, Taf. xxxi, figs. 11, 12a, b.

Two fragments [28267B, 28268] of a single specimen of a small angulate orthoceratid occur at an uncertain level between 1200 ft. and 1220 ft. in depth. It was referred to *Orthoceras* cf. *damesi* Roemer in the original account, and in support of this identification was mentioned the "fine delicate net-work on the outermost layer, which is a characteristic structure of the species".[1] This reticulation, however, is most probably the base of an encrusting Bryozoan. The actual ornament is seen on another portion of the shell. It consists of very fine transverse lines between the longitudinal ribs (Pl. IX, fig. 28b) which is the characteristic ornament of *K. angulatum* (Wahl.). The Missenden species has probably about 18 longitudinal ribs, agreeing more closely in this respect with Wahlenberg's original description than with the majority of the English forms included under this name, which, according to Blake,[2] have from 32 to 42 longitudinal ribs; the transverse striae number 12 to 1 mm. and the spaces between the longitudinal ribs are flat and not concave as in most of the English forms.

I strongly suspect that Roemer's species and that from Missenden are identical and that the former was founded on a misconception of the reticulate 'ornament.' In this case both must be referred to the true *Kionoceras angulatum* (Wahlenberg).

Orthoceras cf. *bullatum* J. de C. Sowerby,

Plate X, fig. 3.

1839. *Orthoceras bullatum* J. de C. Sowerby, in Murchison's 'Silurian System,' pl. v, fig. 29.

1882. *Orthoceras bullatum* J. F. Blake, *op. cit.*, p. 129, pl. xii, figs. 4, 5.

A specimen apparently referable to this species occurs at 1212 ft. [51882]. It is incomplete, showing indications of 12 septa, but has

[1] 'Summary of Progress' for 1915 (*Mem. Geol. Surv.*), 1916, p. 45.
[2] 'A Monograph of the British Fossil Cephalopods,' pt. i, p. 107. London, 1882.

no body chamber or outer shell. The edges of the septa show a forward curvature on the (?) ventral side but are otherwise straight ; their spacing is somewhat irregular and the siphuncle is excentric.

Orthoceras cf. *imbricatum* J. de C. Sowerby

Plate X, fig. 4.

1839. *Orthoceras imbricatum* J. de C. Sowerby, *op. cit.*, p. 620, pl. ix, fig. 2.

Another fragmentary specimen [51883] collected from between 1257 ft. and 1263 ft., resembles *O. imbricatum* J. de C. Sow. in the closeness of the septa, the marked curvature of the sutures, the very gradual rate of increase of the diameter of the shell and the sub-central position of the siphuncle. The external shell is not preserved.

Orthoceras ludense J. de C. Sowerby,
var. *granulatum* var. nov.

Plate X, figs. 5a, b.

Two specimens [51884 and Pl. 4798A] from 1234 ft. agree with *O. ludense* J. de C. Sow. in the straightness of the sutures, in the average distance apart of the septa, and in the rather small and slightly excentric siphuncle. The inner surface of the shell carried numerous, somewhat irregular, rows of minute granulations which have left corresponding rows of shallow pits on the internal casts. This feature does not occur on normal examples of the species. The Missenden form may, therefore, be referred to as *Orthoceras ludense*, var. *granulatum* var. nov., and the specimen figured is considered to be the holotype of the variety [51884].

TRILOBITA

Remains of trilobites are not common. A species of the genus *Calmonia* Clarke is represented by occasional pygidia and one specimen of the posterior portion of a glabella. Apart from these the boring has yielded only a pygidium and a portion of the cranidium of other Phacopids.

Calmonia sp.

Plate X, figs. 6, 7.

Calmonia J. M. Clarke, ' Fosseis Devonianos do Paraná,' *Monogr. Serv. Geol. e Mineral. do Brasil*, vol. i, Rio de Janeiro, 1913, p. 119.

The Missenden form appears to be a new species, but the material is insufficient for a satisfactory diagnosis.

Pygidium convex, wider than long, the ratio of width to length being 3 : 2 ; axis prominent, about one-third of the width of the

pygidium, with nine segments, the first four prominent, the remainder becoming successively less distinct posteriorly, until the last two are almost completely fused; lateral lobes with six well-marked ribs and vestiges of one or two more behind them; the ribs carry faint median grooves; a distinct border edged with six pairs of short backwardly directed spines; a small terminal spine. Dimensions: length 4 mm.; width (at anterior end) 6 mm.

Glabella rather flat; neck ring and also anterior end missing; first two pairs of glabella-lobes very faintly marked; third pair of glabella-furrows deeply impressed, transverse, close to the neck-furrow and extending to the axial furrows, but becoming shallower in that direction.

Occurrence.—Both pygidia and glabella are found at the same level, namely, 1214 feet.

Remarks.—The figured specimens are respectively numbered 51886A and 51871C. The observable characters of both pygidia and glabella, particularly of the former, are undoubtedly those of the Devonian genus *Calmonia* established by Clarke in 1913. The pygidium, like that of *Cryphaeus*, is spinose, but, according to Clarke, *Calmonia* " is a departure from *Cryphaeus* in the possession of a different number and style of lateral spines and, in the type species, a caudal extension . . . ."

In the description of the type-species, *C. signifer* Clarke, the margin of the pygidium is stated to bear " a fringe of six spinules on each side, each broad at the base and tapering rapidly, all directed backward rather than outward " and the glabella to be " quite depressed, scarcely rising above the general surface of the cephalon; the general depression of the glabellar lobes is accompanied by obscuration of the glabellar lobes with the exception of the third."

It will be seen that in these, the essential generic characters, the Missenden form corresponds closely to the genotype.

Phacops sp.

Plate X, fig. 8.

Pygidium semi-elliptical in outline; axis slightly less than one-third the total width, with ten segments, the first four of which are separated by well-marked grooves, the remaining six more closely united and becoming successively smaller and more obscure posteriorly; lateral segments seven in number, swinging backwards near the margin; margin smooth.

Dimensions.—Length 6.5 mm.; width (at anterior end) 10 mm.

Occurrence.—An incomplete pygidium [51885] at an indefinite level between 1200 ft. and 1220 ft. and another one [Pl. 4781A] at 1216 ft.

? Dalmanites sp.

Plate X, fig. 9.

A fragment of the cranidium of a Dalmanitid has been found at 1214 ft. [51887]. The glabella portion shows a flat axial region and indications of three deep glabella-grooves anterior to the neck-furrow. Of the first groove, only the inner end is present, but this shows that the course of the groove was at an angle to the remaining grooves, which are parallel to the neck-furrow. The second and third grooves die out before reaching the axial furrow. The fourth glabella-segment is narrower than those in front, being about equal in width to the neck-ring.

CRUSTACEA

Beyrichia noetlingi Reuter

Plate X, figs. 10, 11, 12.

1885. *Beyrichia noetlingi* G. Reuter, *Zeitschr. d. deutsch. geol. Gesellsch.*, Bd. xxxvii, p. 637, Taf. xxv, fig. 5.

1891. *Beyrichia tuberculata*, var. *noetlingi* T. R. Jones, 'Contributions to Canadian Micro-palaeontology, Part III,' *Geol. and Nat. Hist. Surv. of Canada*, p. 78, pl. xi, figs. 4a, 4b, 5.

Carapace valves sub-oblong at maturity; hinge-line straight, slightly less than the greatest length of the shell, which occurs between the antero-ventral and postero-ventral angles; the anterior lobe broadly crescentic, bearing six strong tubercles having the following arrangement: a large sub-spherical one at the dorsal extremity; below this two smaller rounded ones crossing the valve obliquely upwards from back to front; below these in turn three large tubercles with similar oblique direction, the anterior one isolated from the other two and situated down the anterior slope of the lobe, the remaining two on the crest of the ventral cusp of the lobe. Median sulcus broader and deeper than the posterior; median lobe oval in outline, commencing immediately below the dorsal margin and extending half-way to the ventral margin, increasing in height towards the ventral end; posterior lobe divided into two separate oval protuberances by a strong cross furrow, the dorsal one having its long axis almost at right angles to the hinge, the ventral one with its long axis declined forward; in the female this ventral protuberance is greatly enlarged to form a brood-pouch; a thickened rim surrounding the anterior, ventral and posterior margins; surface of the valves granulated along the marginal rim and on projecting parts (brood-pouch, tubercles, etc.) where the granulations frequently coalesce to form an irregularly wrinkled surface.

Dimensions.—Fully grown specimens have a length of 4.5 mm. and a height of 2.5 mm.

Occurrence.—Abundant in the upper 29 feet of the boring; rather rare below that level. The figured specimens are from 1213 ft. 6 ins.—1213 ft. 9 ins.

Remarks.—The above description (except that of the ornamentation of the valves) is based on internal casts in which the furrows and sulci are more deeply impressed than on the exterior of the shell, giving the lobes and tubercles the appearance of a greater degree of isolation than is actually the case. In all essential features this Missenden species agrees with *B. noetlingi* Reuter, which was described from erratics on the North German Plain near Königsberg. Although not previously found *in situ* in Europe, this species has been described from Arisaig, Nova Scotia, as *B. tuberculata*, var. *noetlingi* by the late Professor T. R. Jones. I have seen specimens from the highest beds of the Stonehouse formation of Arisaig, collected by Professor O. T. Jones. They appear to be identical with the Missenden form.

Kloedenia wilckensiana (Jones)

Plate X, fig. 13.

1855. *Beyrichia wilckensiana* T. R. Jones, *Ann. and Mag. Nat. Hist.*, Ser. 2, vol. xvi, p. 89, pl. v, figs. 17, 18.
1886. *Kloedenia wilckensiana* T. R. Jones and H. B. Holl, *Ann. and Mag. Nat. Hist.*, Ser. 5, vol. xvii, p. 347.

Carapace valves strongly convex, obese ventrally and overhanging the ventral margin; anterior end contracted, posterior end broad; sulci short, the lobes confluent ventrally; anterior and posterior lobes not strongly defined, depressed dorsally; middle lobe the most prominent, broadly oval or almost circular in shape, extending just beyond the dorsal edge and rising above the general level of the surface of the valve; a narrow, flat marginal rim; surface smooth.

Dimensions.—Length 2.5 mm.; height 1.75 mm.

Occurrence.—Fairly generally distributed throughout the boring, becoming abundant in the upper 29 feet.

Remarks.—This form agrees very closely with Jones's original figures, especially his fig. 18. The species was originally described from Scandinavian limestone erratics of the North German Plain. It occurs *in situ* in the Ohhesaare-Pank on Oesel,[1] in the Ramsåsa formation of Scania,[2] but has not been recorded, so far as I am aware, from Gotland. In Britain it is abundant in the Lower Downtonian rocks of Shropshire and elsewhere.[3] Although not previously recorded from North America, this species has been recognized in the material collected by Prof. O. T. Jones from the upper part of the Stonehouse Beds of Arisaig.

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[1] Schmidt, Fr., *Archiv. für die Naturkunde*, 1st Ser., vol. ii, Dorpat, 1858, p. 193.
[2] Moberg, J. C., and K. A. Grönwall, *op. cit.*, p. 66.
[3] Straw, S. H., *Journ. Manch. Geol. Assoc.*, vol. i, pt. 2, 1929, p. 102.

Cytherellina siliqua (Jones)

Plate X, fig. 14.

1855. *Beyrichia siliqua* T. R. Jones, *Ann. and Mag. Nat. Hist.*, Ser. 2, vol. xvi, p. 90, pl. v, fig. 22.

1869. *Cytherellina siliqua* T. R. Jones and H. B. Holl, *Ann. and Mag. Nat. Hist.*, Ser. 4, vol. iii, pp. 216-217, pl. xiv, figs. 1-6.

Carapace valves elongate; dorsal margin convex, ventral margin gently concave; anterior and posterior ends rounded; anterior end narrower than the posterior; external surface smooth and evenly convex, but internal casts show two broad, shallow sulci separating three rounded lobes, the anterior lobe being the smallest and the posterior one the largest.

Dimensions.—Length 1.5 mm.; height 0.75 mm.

Occurrence.—Rare in the upper 29 feet of the boring.

Remarks.—Like the preceding ostracod species this was first known from the North German erratics of Scandinavian limestone. It is found in the British Upper Ludlow rocks and there are varieties of the species in the Wenlock and Woolhope beds. It is known also from the Ramsåsa beds of Scania and the Upper Silurian of Gotland. Of the specimens figured by Jones in 1869 that from the Scandinavian erratic shows the closest approach to the Missenden form of the species in both the form of the lobes and the breadth and straightness of the sulci.

Aparchites oblongus (Jones and Holl)

Plate X, fig. 15.

1865. *Primitia oblonga* T. R. Jones and H. B. Holl, *Ann. and Mag. Nat. Hist.*, Ser. 3, vol. xvi, p. 423, pl. xiii, figs. 14a, b, c.

1889. *Aparchites oblongus* T. R. Jones, *Ann. and Mag. Nat. Hist.*, Ser. 6, vol. iii, p. 384.

Carapace valves oblong, with rounded ends; greatest convexity in the middle of the valve, with a slight flattening towards the margins; ventral margin slightly thickened and gently convex; dorsal margin straighter; a dark spot near the centre of the valve in many specimens appears to indicate the position of a muscle-spot in the interior; surface smooth.

Dimensions.—Length 1.8 mm.; height 1 mm.

Occurrence.—Fairly common in the upper 29 feet of the boring; rare below that level.

Remarks.—In size and form the Missenden specimens resemble *Aparchites oblongus* (Jones and Holl) more closely than any other species of the genus, but there is some variation in the shape of the ends. In some specimens one end is narrower than the other

and the valve shows a greater degree of flattening towards the edges; but as intermediate forms occur there would appear to be no reason for believing that more than one species is represented. This species was first described from Scandinavian limestone erratics on the North German Plain. By Reuter it was noted as occurring in the same erratics as those containing *Beyrichia noetlingi*, and in others containing *Kloedenia wilckensiana* and other ostracods.

Haploprimitia sp.

Plate X, fig. 16.

Carapace valves small, ovate; anterior end slightly narrower than the posterior; surface smooth, evenly convex; a simple vertical slit-like median sulcus in the dorsal half of the valve.

Dimensions.—Length 1 mm.; height 0.75 mm.

Occurrence.—A single specimen [51877B] at 1245 ft. 6 ins.—1246 ft.

Remarks.—This small shell is Primitian in aspect, but differs from *Primitia* in the absence of low nodes at the side of the sulcus and of a border to the free edge of the valve.[1]

In addition to the species of ostracods described above, there are one or two minute smooth forms of uncertain affinities. For the present they have been left undescribed.

Report on the Fish-remains from the Little Missenden Boring

by Sir Arthur Smith Woodward, F.R.S.

The early Palaeozoic fish-remains from the Missenden Boring are much disintegrated and seem to have been rolled before they were buried. They are, however, sufficiently well preserved to exhibit their microscopical structure. The specimens are numbered, and in the following report on the collection the numbers of illustrative examples are given in brackets.

Thelodus Agassiz. Clusters of small quadrangular scales [Pl. 4807, Pl. 4809, Pl. 4822, 51863] and many scattered specimens may be either Thelodont or Acanthodian. Microscope sections show that most of them are referable to *Thelodus*. One or two specimens with irregular base may perhaps be tubercles from the dermal plates of *Psammosteus*.

Climatius Agassiz. This primitive Acanthodian is represented by numerous fragmentary fin-spines, with two examples of their support, and a few plates from the top of the head. The Acanthodian scales already mentioned may also be assigned to the same genus, though they have no distinctive characters. The fin-spines are

[1] Compare Ulrich, E. O., and R. S. Bassler, *Maryland Geol. Surv.*, Silurian, 1923, p. 297.

truncated as usual at the base, without any inserted portion. They are shown to be laterally compressed and hollow [Pl. 4832], and the very open texture of their tissue is seen both in broken specimens [Pl. 4830, Pl. 4835] and in a microscope section [M/877]. Their outer surface is marked by smooth, rounded longitudinal ridges, which are closely arranged and number at least 13 at the base [Pl. 4844] but are reduced in the more slender distal part by the tapering out of some of them [51890]. None of these ridges are tuberculated or crossed by growth-lines, and no posterior denticles have been observed in any spine. Several specimens show the base sufficiently well to prove that the fin-spines were strongly inclined backwards. The two best preserved specimens, which are of nearly the same length (36 mm.), may well have been the anterior and posterior dorsal fin-spines of the same fish. The anterior spine (Pl. 4792 and 51889, Plate X, fig. 17) is strongly curved and broader at the base than the posterior spine (Pl. 4800 and 51890, Plate X, fig. 18) which is nearly straight and slender at the apex. Several fragments of both these types of spine occur ; and one cross-section of a small paired spine can also be seen [Pl. 4807], showing its internal cavity not closed behind, and the anterior half of its wider side not ridged but smooth. The basal support lying close to one fragment of spine [51891, Pl. 4802] is of the type well known in *Climatius*. The specimen (Plate X, fig. 19) is too much fractured to show its exact shape, but it is clearly expanded into a thin lamina at the end for contact with the base of the spine, and the rest of the support is a thick, rounded, hollow rod. A small quadrangular plate, exposed from the smooth inner face [Pl. 4799], may be a head plate of *Climatius*, and a partly disintegrated plate of irregular shape about 8 mm. wide and 15 mm. long [Pl. 4800] may perhaps belong to the cranial roof ; but two small plates which are ornamented with closely arranged, minute, rounded tubercles, may almost certainly be referred to this position. One of these [Pl. 4819] is only 3 mm. in length, but the other (51892, Pl. 4810, Plate X, fig. 20) is an elongated plate 10 mm. in length by 4.5 mm. in width, truncated at one end and with one angle bevelled off at the other end.

Psammosteus Agassiz. The largest fragment in the collection is an apparently waterworn straight rod of dense, solid bone, about 13 mm. in width and 6 mm. in maximum thickness [51893]. It is not bilaterally symmetrical (Plate X, fig. 21), and each wide face is raised into a longitudinal ridge, that of one face being in the median line, that of the opposite face slightly to one side and more acute than the other ridge. Much of the outer face is exposed, without any ornament, but it may owe its smoothness to abrasion. At first sight, the fragment appears to be part of the armour of a large Arthrodiran, but a microscope section (Plate X, fig. 22), shows that it has the structure of the dermal plates of *Psammosteus*.[1] There can, indeed, be no doubt that it belongs to a *Psammostean*.

[1] Kiaer, J., ' Upper Devonian Fish Remains from Ellesmere Land,' Rep. 2nd Norwegian Arctic Exped. in Fram, 1898-1902, No. 33, p. 35, pl. vi (1915).

The specimen is too incomplete to be assigned to its place in the skeleton; and that it lay for some time before it was buried is shown by the multitude of irregular vermiculating tubules which radiate from the vascular spaces and must have been made by some boring parasite, probably the mycelium of a fungus. Each of these tubules in the microscope section is tipped by an opaque dot.

All the three generic groups thus identified range from the Ludlow Bone-bed upwards into the Devonian, so that it is difficult to use the new fossils for determining the precise horizon to which they belong. As, however, the ridges on the spines of *Climatius* are smooth, it is more likely that these spines are of Lower Devonian than of Downtonian age: in the known Silurian and Downtonian spines, the ridges are strongly notched, marking the limits of the tubercles of which they must have been originally formed. As, moreover, the fragment of *Psammosteus* is much too large to be referred to any Downtonian species hitherto discovered, it is probably, at the earliest, Lower Devonian. If, therefore, the horizon in the Missenden Boring from which the fish-remains were obtained is shown by other fossils to be Downtonian, these remains indicate a fauna of an unusually advanced type. [A.S.W.]

Faunal and Stratigraphical Summary

The upper 29 feet of the Palaeozoic core (*i.e.*, from 1200 ft. to 1229ft.) are richest in invertebrate remains, of which brachiopods and ostracods are the dominant types. *Chonetes novascoticus*, var. *missendenensis* var. nov. and *Beyrichia noetlingi* Reuter outnumber all the rest, the latter being particularly abundant. There are no samples from between the depths of 1229 ft. and 1233 ft.

The lower 30 feet (*i.e.*, from 1233 ft. to 1263 ft.) are characterized by the presence of fragmentary fish-remains and a greater development of gastropods and lamellibranchs. They contain the same brachiopod-ostracod fauna, but in greatly reduced numbers.

On faunal grounds, therefore, the Palaeozoic rocks of Missenden may be conveniently classified into :—

(ii) the upper 29 feet, or the *Beyrichia noetlingi* Beds.
(i) the lower 30 feet, or the Fish Beds.

(i) *The Missenden Fish Beds*

These beds differ slightly in lithology from the upper beds, being more gritty, less calcareous and of a rather darker grey colour. The fish-remains, though scattered throughout this part of the core, occur most abundantly in a one-foot band at 1245 ft. which " almost merits the designation of bone-bed."[1]

Immediately below this band, at 1245 ft. 6 in. to 1246 ft., occurs another band crowded with *Plectonotus trilobatus* (J. de C. Sow.)

[1] ' Summary of Progress ' for 1915 (*Mem. Geol. Surv.*), 1916, p. 45.

and containing also, quite commonly, *? Ctenodonta hercynica* Beushausen and *Hormotoma missendenensis* sp. nov. *Plectonotus trilobatus* is restricted to this level.

The fish-remains include *Thelodus*, Acanthodian spines and *Psammosteus*. They are described by Sir Arthur Smith Woodward, F.R.S., in the accompanying report on the fish-remains.

The following lamellibranch species are confined to the Fish Beds :—

Modiolopsis *cf.* complanata (*J. de C. Sow.*)
Nuculites corrugata *Williams*
? Ctenodonta hercynica *Beushausen*

Lingula zigzag sp. nov. appears to be restricted to this portion of the boring, as also are *Orthoceras* cf. *imbricatum* and *O. ludense*, var. *granulatum* var. nov.

(ii) *The* Beyrichia noetlingi *Beds*

The fossils are largely confined to thin light-coloured shelly limestone-bands and, except for the ostracods, are in a fragmentary condition. The most important forms from the point of view of correlation are the brachiopods, ostracods and trilobites.

The ostracods belong chiefly to the following species :—

Beyrichia noetlingi *Reuter*
Kloedenia wilckensiana (*Jones*)
Cytherellina siliqua (*Jones*)
Aparchites oblongus (*Jones and Holl*)

C. siliqua appears to be confined to these beds, but the others extend downwards into the Fish Beds.

The brachiopods include :—

Lingula missendenensis *sp. nov.*
Pholidops antiqua (*Schloth.*)
Dalmanella missendenensis *sp. nov.*
Chonetes novascoticus, *var.* missendenensis *var. nov.*
Camarotoechia glomerosa *McLearn*

They all pass down into the Fish Beds.

The trilobites are all Phacopids and are confined to the *Beyrichia noetlingi* Beds. The point of greatest interest about them is the occurrence of a species of the Devonian genus *Calmonia* at 1214 ft. The cephalopod species *Kionoceras angulatum* (Wahl.) and *Orthoceras* cf. *bullatum* J. de C. Sow. are represented by a single specimen of each.

The accompanying table (pp. 136-7) shows the vertical distribution in the boring of all the species recognized.

Age and Correlation of the Fauna

Although the Palaeozoic strata under Little Missenden fall naturally into two divisions based on the abundance of fish-remains in the lower portion and of invertebrate fossils in the upper, there

LITTLE MISSENDEN BORING

Vertical Distribution of Fossils

Name of Fossil	Depth below Surface														
	1204 ft. and 1206 ft.	1212 ft. and 1213 ft. 6 ins.—1213 ft. 9 ins.	1214 ft.	1216 ft.	1219 ft.	Indefinite levels 1200 ft.—1220 ft.	1223 ft. and 1224 ft.	1225 ft. 6 ins.	1229 ft.	1233 ft. and 1234 ft.	1243 ft. and 1245 ft.	1245 ft. 6 ins.—1246 ft.	1250 ft.—1252 ft.	1257 ft.—1263 ft.
CRINOIDEA														
Stem fragments and columnals ...	—	—	—	—	×	×	×	×	—	×				
ANNELIDA														
Cornulites serpularius *Schloth.* ...	—	—	—	×	×	—	—	—	—	×				
Worm burrows	×	—	—	—	—	×	×	×						
BRYOZOA														
Rhopalonaria sp.	—	—	—	—	—	—	×	×						
BRACHIOPODA														
Camarotoechia glomerosa *McLearn* ...	×	×	×	—	—	×	×	×	—	×	×	—	—	×
Chonetes novascoticus *Hall, var.* missendenensis *var. nov.*	×	×	×	×	—	×	×	×	×	×	×			
Dalmanella missendenensis *sp. nov.* ...	×	×	×	—	—	—	×	×	×	×	×			
Lingula missendenensis *sp. nov.* ...	—	—	—	—	—	×	—	—	—	×				
Lingula zigzag *sp. nov.*	—	—	—	—	—	—	—	—	—	—	—	×		
Lingula fragments	—	—	—	×	×	—	—	×	×	×	—	×	×	×
Orbiculoidea crucifera *sp. nov.* ...	?	—	—	—	—	—	—	—	—	—	×	?		
Orbiculoidea sp.	—	—	—	—	—	—	—	—	—	×	—	—	—	×
Pholidops antiqua (*Schloth.*)	—	—	×	—	—	—	—	—	—	—	—	×		
LAMELLIBRANCHIATA														
Anodontopsis sp.	—	—	—	—	—	×								
? Ctenodonta hercynica *Beush.*... ...	—	—	—	—	—	—	—	—	—	—	—	×		
? Goniophora sp.	—	—	—	—	—	×								
Modiolopsis *cf.* complanata (*J. de C. Sow.*)	—	—	—	—	—	—	—	—	—	—	—	—	—	×
? Nucula sp.	—	—	—	—	—	—	—	—	—	×				
Nuculites *cf.* antiqua (*J. de C. Sow.*) ...	—	—	×											
Nuculites *cf.* coarctata (*Phillips*) ...	—	—	—	—	—	×								
Nuculites corrugata *Williams* ...	—	—	—	—	—	—	—	—	—	×				
Palaeoneilo attenuata (*Hall*)	—	—	—	—	—	—	—	—	—	—	×			
? Palaeopecten sp.	—	—	—	—	—	×								
GASTROPODA														
Hormotoma *cf.* articulata (*J. de C. Sow.*)	—	—	×	—	—	×	—	—	—	×	—	×		
Hormotoma missendenensis *sp. nov.* ...	—	—	—	—	—	—	—	×	×	×	×	×		
Plectonotus trilobatus (*J. de C. Sow.*) ...	—	—	—	—	—	—	—	—	—	—	—	×		
Tentaculites annulatus *Schloth.* ...	—	×	×	×	×	×	×	—	—	×	×	×	×	
	Noetlingi Beds									Fish Beds				

LITTLE MISSENDEN BORING
Vertical Distribution of Fossils

Name of Fossil	Depth below Surface														
	1204 ft. and 1206 ft.	1212 ft. and 1213 ft. 6 ins.—1213 ft. 9 ins.	1214 ft.	1216 ft.	1219 ft.	Indefinite levels 1200 ft.—1220 ft.	1223 ft. and 1224 ft.	1225 ft. 6 ins.	1229 ft.	1233 ft. and 1234 ft.	1243 ft. and 1245 ft.	1245 ft. 6 ins.—1246 ft.	1250 ft.—1252 ft.	1257 ft.—1263 ft.
CEPHALOPODA														
Kionoceras angulatum (*Wahl.*) ...	—	—	—	—	—	×								
Orthoceras *cf.* bullatum *J. de C. Sow.* ...	—	×												
Orthoceras *cf.* imbricatum *J. de C. Sow.*	—	—	—	—	—	—	—	—	—	—	—	—	—	×
Orthoceras ludense *J. de C. Sow., var.* granulatum *var. nov.*	—	—	—	—	—	—	—	—	—	×				
TRILOBITA														
Calmonia sp.	—	—	×											
? Dalmanites sp....	—	—	×											
Phacops sp.	—	—	—	×	—	×								
CRUSTACEA														
Aparchites oblongus (*Jones and Holl*)...	—	—	×	—	×	×	?	—	—	×	—	×		
Beyrichia noetlingi *Reuter*	×	×	×	×	×	×	×	—	×	×	?			
Cytherellina siliqua (*Jones*)	—	—	×	—	×									
Haploprimitia sp.	—	—	—	—	—	—	—	—	—	—	—	×		
Kloedenia wilckensiana (*Jones*) ...	—	×	×	×	×	—	×	—	—	×	×			
PISCES														
Climatius sp.	—	—	—	—	—	—	—	—	—	×	×	×	×	×
Psammosteus sp.	—	—	—	—	—	—	—	—	—	—	×			
Thelodus sp.	—	—	—	—	—	—	—	—	—	—	×	×		
Fish fragments	—	—	—	—	—	—	—	—	—	×	×	×	×	×
	Noetlingi Beds									Fish Beds				

is no reason to suppose that they belong to deposits of more than one geological age. Reference to the list of fossils will show that many of the characteristic species are found in both divisions and that those of apparently limited range, such as the cephalopods and lamellibranchs, are represented mostly by rare specimens belonging to species which are either new, or which, elsewhere, are known to be long-ranging forms. A slight difference in physical conditions would be sufficient to account for the faunal differences observed between the upper and lower portions of the core examined.

The evidence of age revealed by the fish-remains has been clearly stated by Sir Arthur Smith Woodward. It gives fairly definite indications in favour of a post-Downtonian date for the

fauna. The evidence of the invertebrates has now to be considered.

1. The description of the fauna given in an earlier section makes it clear that the previous correlation of these beds with the Upper Whitcliff Flags can no longer be maintained. The ostracods, brachiopods, trilobites and most of the lamellibranchs are quite distinct from those of the Upper Ludlow. The cephalopods, it is true, have been compared with species occurring in the Upper Ludlow, but these, for reasons stated above, are of doubtful correlation value.

2. On the same grounds the case for a Lower Downtonian age breaks down, but not so completely, since the Missenden fauna possesses certain important elements in common with the Lower Downtonian, namely, *Kloedenia wilckensiana*, *Plectonotus trilobatus*, and *Modiolopsis* cf. *complanata*. The presence of these species in the fauna points undoubtedly to Downtonian affinities, but the rest of the fauna has so little in common with the Lower Downtonian fauna of Shropshire and the Welsh Borderland that a correlation of the two appears to be out of the question.

3. The Missenden fauna contains only slight evidence of relationship with the typical marine Lower Devonian. The trilobite genus *Calmonia* is known, elsewhere, only from the Lower Devonian of South America and South Africa and *Ctenodonta hercynica* occurs in the Rhenish Lower Devonian. Apart from these, no undoubted purely Lower Devonian elements are present.

4. The great abundance of *Beyrichia noetlingi* strongly suggests a correlation with the *Noetlingi*-kalk of Reuter. The latter term was applied by Reuter[1] to certain erratics, found by him near Königsberg in East Prussia, which were distinguished by the presence of this ostracod in large numbers. Associated fossils were stated to be *Chonetes*, *Rhynchonella*, *Primitia* (= *Aparchites*) *oblonga* and *Onchus*.

Reuter described several other types of ostracod limestone erratics from the same region, each with its characteristic assemblage of ostracod species. It is, perhaps, significant that, whereas in the case of many of the erratics he identified the associated brachiopods specifically as *Chonetes striatella*, *Rhynchonella nucula*, etc., those of the *Noetlingi*-kalk received merely generic names. Was this because he recognized their specific distinctness? It is unfortunate, for the present investigation, that more is not known of the complete fauna of these East Prussian erratics.

Reuter was able to correlate many of the limestone erratics with similar limestones occurring *in situ* on the islands of Gotland and Oesel, but was unable to discover a source of origin for the *Noetlingi*-kalk. He concluded that, in all probability, it was derived, therefore, from the floor of the Baltic Sea. Since *B. noetlingi* has not been recorded subsequently, either from the islands or the mainland of the Baltic region, this obviously reasonable conclusion

[1] *Op. cit.*, p. 669.

appears to be correct. Now since, as Schmidt has shown,[1] the arrangement of the rocks in this region is synclinal, the absence of the *Noetlingi*-kalk from Gotland and Oesel and its presence on the floor of the Baltic can be explained on the assumption that it occurs only in the higher beds in the centre of the syncline and is thus younger than any of the limestones on either island. It seems doubtful whether limestones younger than Upper Ludlovian appear on Gotland, but on Oesel the highest beds are the well-known limestones (Etage K) with fish-remains, of the Ohhesaare-Pank. These are almost certainly Lower Downtonian.[2] They were correlated with the English Tilestones by Schmidt as long ago as 1858.[3] The *Noetlingi*-kalk and, presumably, therefore the Missenden fauna also, would thus appear to be of post-Lower Downtonian date. How much later it is impossible to say, except that the age is probably pre-Middle Old Red Sandstone, since on the mainland of Esthonia the next younger rocks are sandstones with *Coccosteus*, *Asterolepis*, etc., which rest unconformably on successively younger formations of the Cambrian, Ordovician, and Silurian as they are traced westwards towards the Baltic.[4]

5. Certain of the most distinctive elements of the Missenden fauna occur also, on the other side of the Atlantic, in the higher beds of the Stonehouse formation of Arisaig, Nova Scotia. Species common to the two faunas include :—

Cornulites serpularius *Schloth.*
Chonetes novascoticus *Hall* (large form)
Camarotoechia glomerosa *McLearn*
Beyrichia noetlingi *Reuter*
Kloedenia wilckensiana (*Jones*)
Plectonotus trilobatus (*J. de C. Sow.*)
Kionoceras angulatum (*Wahl.*)
Palaeoneilo attenuata (*Hall*)

Whilst it does not appear possible to carry the comparison of the two faunas further than this, yet, considering the distance which separates them, the possession of so many elements in common is highly suggestive, if not of actual contemporaneity, at least of approximate equivalence in age.

Reviewing the evidence of both fish and invertebrates as to the age and correlation of the fauna, we see that the invertebrates indicate an age not earlier than late Downtonian, whilst the fish-remains point to post-Downtonian. The age of the fauna would appear to be, therefore, either late Downtonian or post-Downtonian. It is not possible at present to date the fauna more precisely. Its closest known correlatives are the *Noetlingi*-kalk of Reuter and the higher beds of the Stonehouse formation of Nova Scotia. To what portion, if any, of the typical marine Lower Devonian it corresponds cannot be determined, though the presence of two Lower

[1] *Quart. Journ. Geol. Soc.*, vol. xxxviii, 1882, pp. 530, 531.
[2] Cf. L. D. Stamp, *Geol. Mag.*, 1923, p. 405.
[3] *Archiv. für die Naturkunde*, 1st Ser., vol. ii, Dorpat, 1858, p. 179.
[4] Schmidt, Prof. F., *Quart. Journ. Geol. Soc.*, vol. xxxviii, 1882, p. 530 and Map (Pl. xxiii).

Devonian forms, each of which is common at a different level in the boring, suggests the existence of contemporaneous Lower Devonian deposits elsewhere.

Additional Notes on some Fish-remains from the Missenden Boring

By Sir Arthur Smith Woodward, F.R.S.

51889 (counterpart Pl. 4792). A much-abraded very oblique hollow spine of *Climatius*, bluntly rounded at front end of base, not showing external surface.

Pl. 4799. Small quadrangular plate, inner view, doubtfully of *Climatius*.

51891. Base of spines showing at least 10 smooth ridges wider than interspaces; also (displaced) one of the characteristic cartilage basal supports (*Climatius*). Counterpart is Pl. 4802.

Pl. 4803. Straight, slender spine of *Climatius*. All ridges smooth. Same as good spine 51890.

Pl. 4807. Fragments of hollow spines of *Climatius* showing open texture. On other side a cross-section of a spine which is not bilaterally symmetrical and is widely open behind. Also scales of *Thelodus*, etc.

51890 (counterpart Pl. 4800). Good straight spine of *Climatius*.

Pl. 4809. Mass of scales of *Thelodus* or Acanthodian. Fragments of spines on both sides.

Pl. 4810 (counterpart 51892). Impression of head plate of *Climatius*; also basal support of spine.

Pl. 4811. Splintered base of spine of *Climatius* with very large central cavity.

Pl. 4812. Fragment of straight spine (*Climatius*).

Pl. 4813. Fragments of hollow spines and scales.

51863. Mass of scales and fragment of spine.

Pl. 4817, 51892, 51893. Fit together. Plate of *Psammosteus*, in pieces, also a micro-slide of the same. On the other side an impression of the head plate of *Climatius* [Pl. 4810].

Pl. 4819. Small tuberculated head plate of *Climatius*.

51877. *Thelodus* and fragments of spines of *Climatius*.

Pl. 4822. The same.

Pl. 4830. Fragment of spine showing coarse open tissue (*Climatius*).

Pl. 4831. Base of hollow spine showing texture.

Pl. 4832. The same.

Pl. 4833. Hollow base of very oblique spine and apical part of slender straight spine (*Climatius*).

Pl. 4835. Fragments of much abraded spines, one slender apex very straight (*Climatius*).

Pl. 4844. Base of spine showing 13 or more ridges on side, all smooth (*Climatius*).

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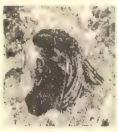
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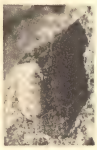
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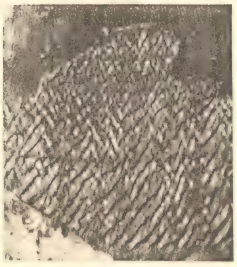
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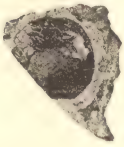
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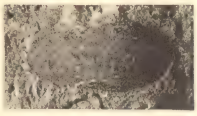
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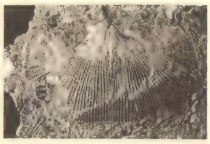
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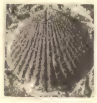
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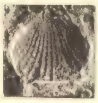
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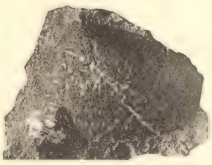
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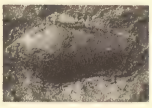
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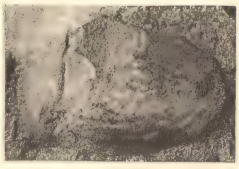
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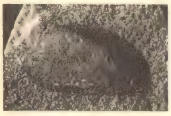
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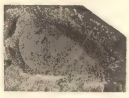
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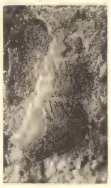
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28*a*

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PALAEOZOIC FOSSILS FROM THE LITTLE MISSENDEN BORING.

EXPLANATIONS OF PLATES IX AND X

All figures are in natural size except where otherwise stated. The specimens are all preserved in the collection of the Geological Survey in London; their register-numbers are quoted in brackets.

PLATE IX

Fig.

1. *Cornulites serpularius* Schlotheim, [51857], page 113.
2. *Rhopalonaria sp.*, × 4. [51858], page 114.
3a. *Lingula missendenensis* sp. nov., holotype, × 2. [51859], p. 114.
3b. *Lingula missendenensis* sp. nov., portion of holotype enlarged to show the fine, wavy, concentric wrinkling of the shell; × 15.
4a. *Lingula zigzag* sp. nov., holotype, × 5. [51860A], page 115.
4b. *Lingula zigzag* sp. nov., ornamentation of the holotype, × 30.
5. *Orbiculoidea crucifera* sp. nov., holotype; ventral valve showing the (incomplete) cruciform pedicle elevation and the impression of a portion of the outer surface, × 4. [51861A], page 115.
6. *Orbiculoidea sp.*, dorsal valve. [51862], page 116.
7. *Pholidops antiqua* (Schlotheim), internal cast, showing impressions of the strongly marked bilobed muscle callosity and the more faintly marked smaller pair immediately in front, × 4. [51863], page 116.
8. *Dalmanella missendenensis* sp. nov., dorsal valve, exterior. [51864], page 116.
9. *Dalmanella missendenensis* sp. nov., syntype A, dorsal valve, internal cast, [51865].
10. *Dalmanella missendenensis* sp. nov., syntype B, ventral valve, internal cast, [51866].
11. *Chonetes novascoticus* Hall, var. *missendenensis* var. nov., holotype of variety, a partially decorticated ventral valve. [51867], page 117.
12. *Camarotoechia glomerosa* McLearn, dorsal valve, internal cast. [51868A], page 118.
13. *Camarotoechia glomerosa* McLearn, ventral valve, internal cast, [51868B].
14. *? Ctenodonta hercynica* Beushausen, right valve; internal cast with fragments of shell attached. [51861B], page 119.
15. *? Nucula sp.*, right valve, internal cast. [51869], page 120.
16. *Palaeoneilo attenuata* (Hall), left valve, internal cast. [51870] page 120.
17. *Nuculites* cf. *antiqua* (J. de C. Sowerby), right valve, internal cast. [51871A], page 121.
18. *Nuculites* cf. *coarctata* (Phillips), right valve; partly shell, partly internal cast. [51872A], page 121.
19. *Nuculites corrugata* Williams, left valve, internal cast. [51873], page 122.
20. *Modiolopsis* cf. *complanata* (J. de C. Sowerby), left valve, internal cast. [51874], page 122.
21. *? Goniophora sp.*, left valve, internal cast. [51875], page 123.
22. *Anodontopsis sp.*, right valve, internal cast. [51872B], page 123.
23. *Hormotoma* cf. *articulata* (J. de C. Sowerby), young shell showing slightly depressed slit-band bounded by raised threads, × 2. [51876], page 124.
24. *Hormotoma* cf. *articulata* (J. de C. Sowerby), a more mature specimen showing eight whorls. [51877A].
25. *Hormotoma missendenensis* sp. nov., holotype, × 2. [51878], page 124.
26. *Plectonotus trilobatus* (J. de C. Sowerby), umbilical aspect. [51879], page 125.
27. *Plectonotus trilobatus* (J. de C. Sowerby), the same specimen, dorsal aspect.
28a. *Kionoceras angulatum* (Wahlenberg), external mould of part of the specimen. [28267B], page 126.
28b. *Kionoceras angulatum* (Wahlenberg), exterior of another fragment of the same specimen, showing the fine transverse ornament, × 8.

PLATE X

Fig.

1a. *Tentaculites annulatus* Schlotheim, external mould of the mature portion of a shell. [51880], page 125.

1b. *Tentaculites annulatus* Schlotheim, plasticine cast of the same specimen.

2. *Tentaculites annulatus* Schlotheim, portion of another specimen enlarged to show the fine annular growth-lines seen between the annulations, × 8. [51881A].

3. *Orthoceras* cf. *bullatum* J. de C. Sowerby. [51882], page 126.

4. *Orthoceras* cf. *imbricatum* J. de C. Sowerby. [51883], page 127.

5a. *Orthoceras ludense* J. de C. Sowerby, var. *granulatum* var. nov., holotype of new variety, almost entirely preserved as an internal cast. [51884], page 127.

5b. *Orthoceras ludense* J. de C. Sowerby, var. *granulatum* var. nov., a portion of the internal cast of one of the chambers of the same specimen, enlarged to show the irregular rows of small pits formed by the granulations on the inner surface of the shell; × 12.

6. *Calmonia sp.*, fragment of a glabella, × 2. [51871C], page 127.

7. *Calmonia sp.*, pygidium (interior view), × 2. The figure may appear convex but the specimen is hollow. Five spines may be seen on each side, but they are not all paired. A complete pygidium would show six pairs. [51886A].

8. *Phacops sp.* An incomplete pygidium. [51885], page 128.

9. *? Dalmanites sp.*, portion of a glabella. [51887], page 129.

10. *Beyrichia noetlingi* Reuter, internal cast of an incomplete left valve, × 3. [28269], page 129.

11. *Beyrichia noetlingi* Reuter, internal cast of a right valve, × 3. [28270].

12. *Beyrichia noetlingi* Reuter, a left valve with the shell still preserved on the anterior lobe. This shows the presence of granulations in between the tubercles on the outer surface of the shell, × 3. [51888].

13. *Kloedenia wilckensiana* (Jones), right valve, × 6. [51881B], page 130.

14. *Cytherellina siliqua* (Jones), internal cast of a right valve, × 5. [51886B], page 131.

15. *Aparchites oblongus* (Jones and Holl), right valve, × 5. [51881C], page 131.

16. *Haploprimitia sp.*, right valve, × 5. [51877B], page 132.

17. *Climatius sp.*, anterior spine. [51889], page 133.

18. *Climatius sp.*, posterior spine. [51890], page. 133.

19. *Climatius sp.*, fragment of spine and basal support. [51891], page 133.

20. *Climatius sp.*, head-plate. [51892], page 133.

21. *Psammosteus sp.*, cross-section of bone. [51893], page 133.

22. *Psammosteus sp.*, micro-section of the same, × 4. [M/876].

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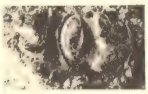
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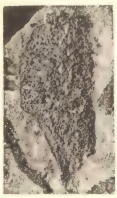
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